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Krause et al.

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[54] **FLEXIBLE SHAFT**

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[21] Appl. No.: **08/680,628**

[22] Filed: **Jul. 17, 1996**

Related U.S. Application Data

[60] Provisional application No. 60/006,064, Oct. 23, 1995, and provisional application No. 60/001,475, Jul. 18, 1995.

[51] **Int. Cl.**[7] **A61B 17/32**

[52] **U.S. Cl.** **606/80**; 606/180; 464/78

[58] **Field of Search** 606/80, 85, 84, 606/79, 81, 96, 130; 464/78, 54, 57, 58, 59, 97; 408/210, 199

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,515,366	7/1950	Zublin .	
4,646,738	3/1987	Trott .	
4,706,659	11/1987	Matthews et al. .	
4,751,922	6/1988	DiPietroopolo .	
5,108,411	4/1992	McKenzle .	
5,122,134	6/1992	Borzone et al. .	
5,387,218	2/1995	Meswania	606/80
5,488,761	2/1996	Leone .	
5,527,316	6/1996	Stone et al.	606/80

OTHER PUBLICATIONS

"New Twists for Flexible Shafts", Paul Dvorak, Machine Design, Sep. 7, 1989 p.145–146.

"Flexible Shafts Make Obstacles Disappear", Jul. 1993, Figure 1 Brian Parlato, S.S. White Technologies Inc., Power Transmission Design.

Suhner Catalog pp. 6,15 & 16 "Flexible Shafts Spiral Bevel Gears", Undated.

S.S. White Technologies Inc. Catalog p. 4–5 "Ready–Flex", Undated.

Primary Examiner—Michael Buiz

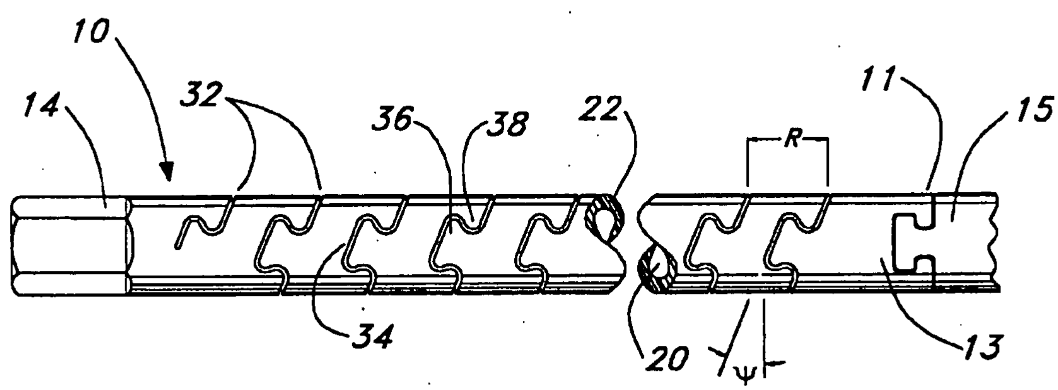
Assistant Examiner—David O. Reip

Attorney, Agent, or Firm—Sheldon H. Parker

[57] **ABSTRACT**

An improved flexible shaft used in the reaming of the medullary space in bones is described. The shaft is comprised of a solid element with a longitudinal bore the entire length and an appropriately formed slot which extends spirally around the shaft either continuously or segmentally. Attached to the shaft's opposite ends respectively, are a cutting head and a means of connecting the shaft to a driving mechanism.

21 Claims, 7 Drawing Sheets



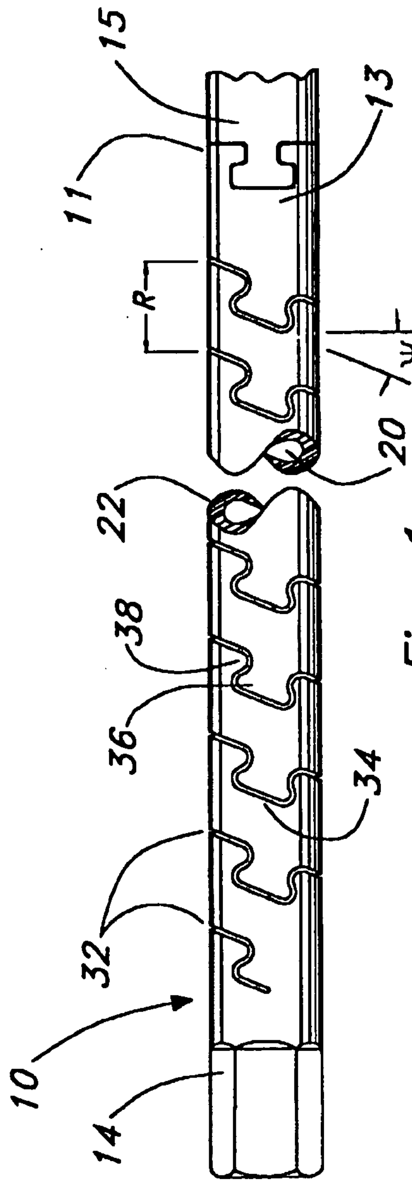


Fig. 1

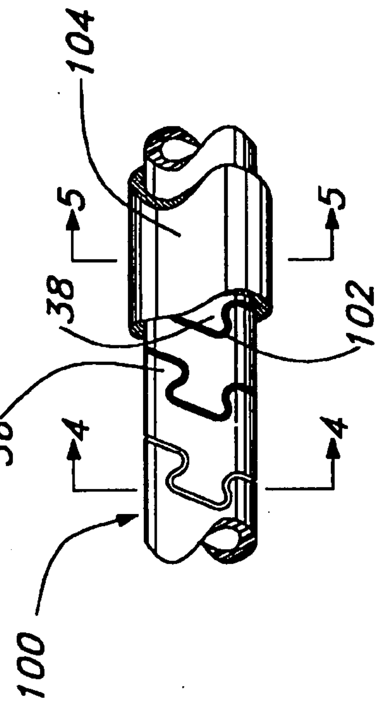


Fig.2

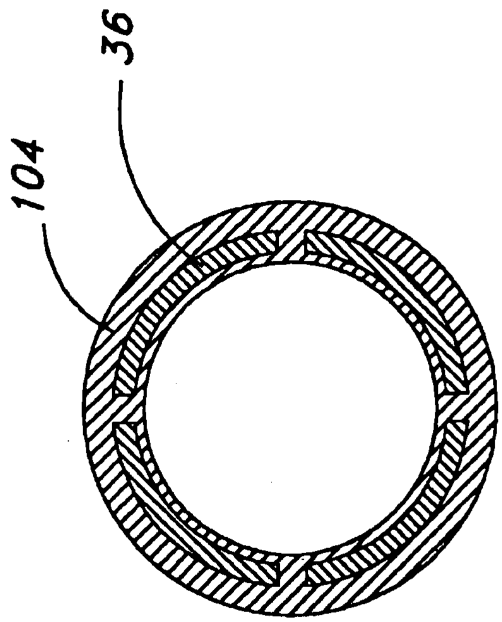


Fig.5

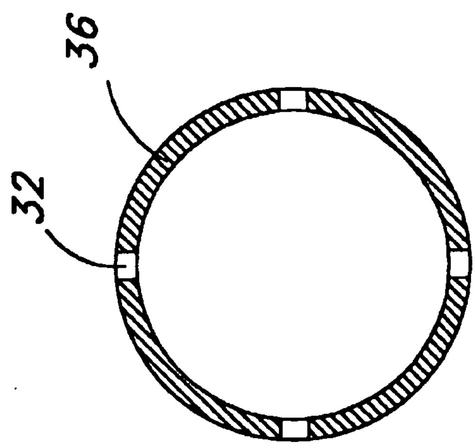


Fig.4

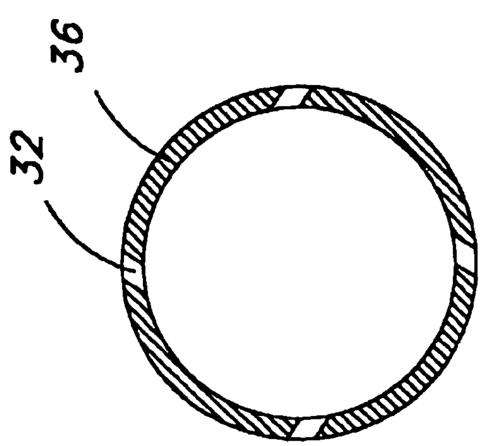


Fig.3

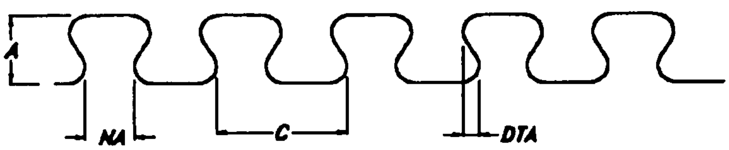


Fig.6A

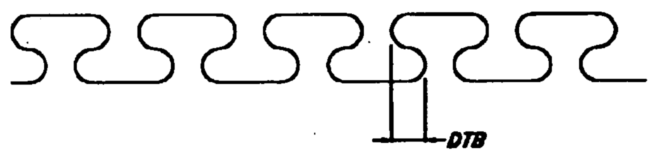


Fig.6B

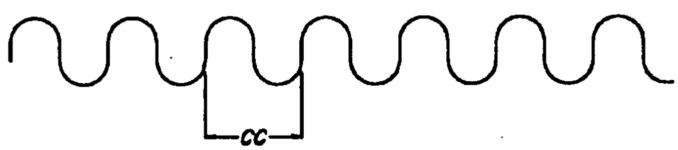


Fig.6C

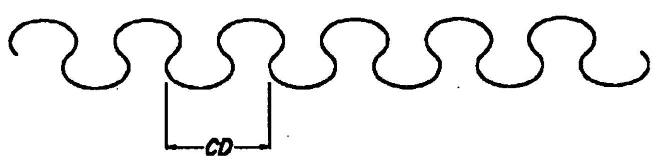


Fig.6D

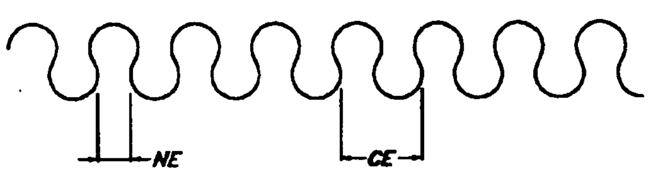


Fig.6E

Fig.6F

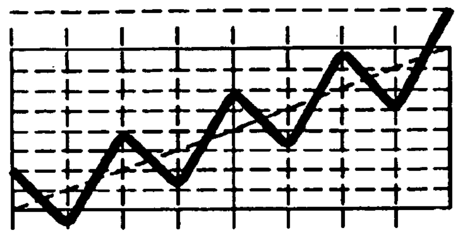
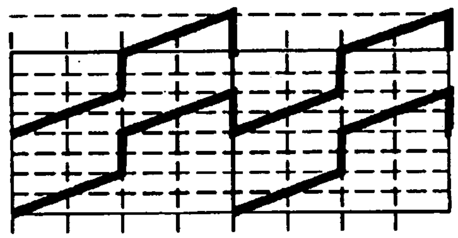


Fig.6G



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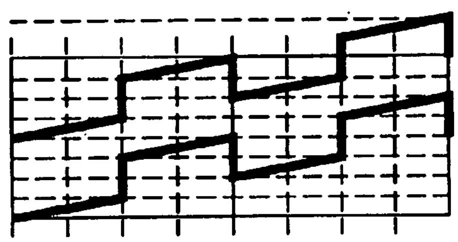

Fig.6I

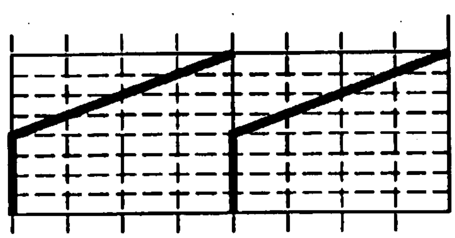

Fig.6J

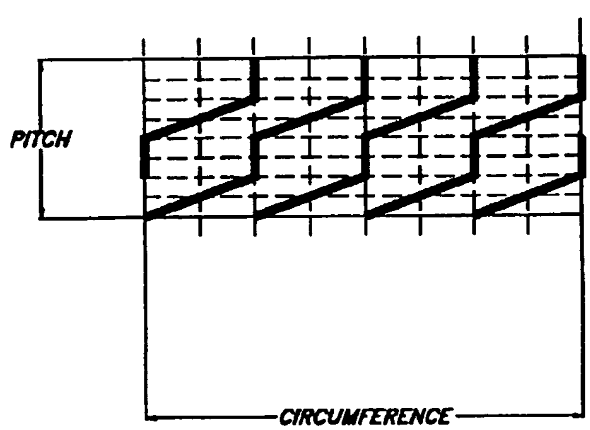

Fig.6K

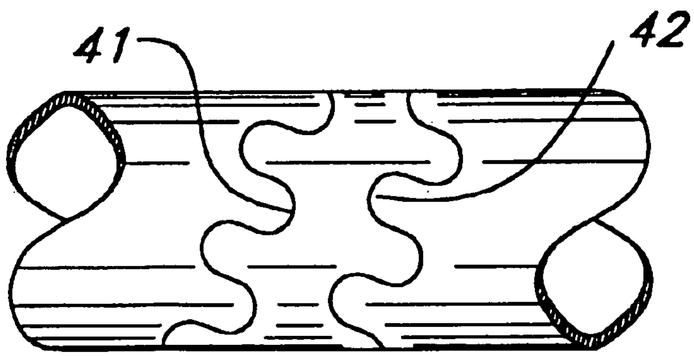

Fig. 7A

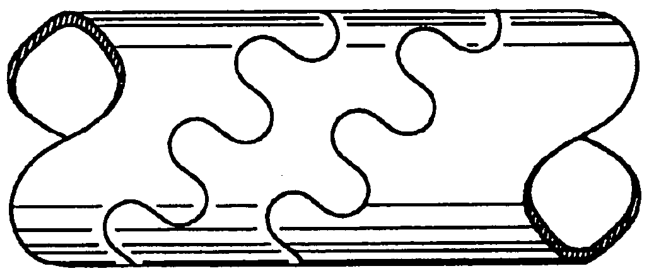

Fig. 7B

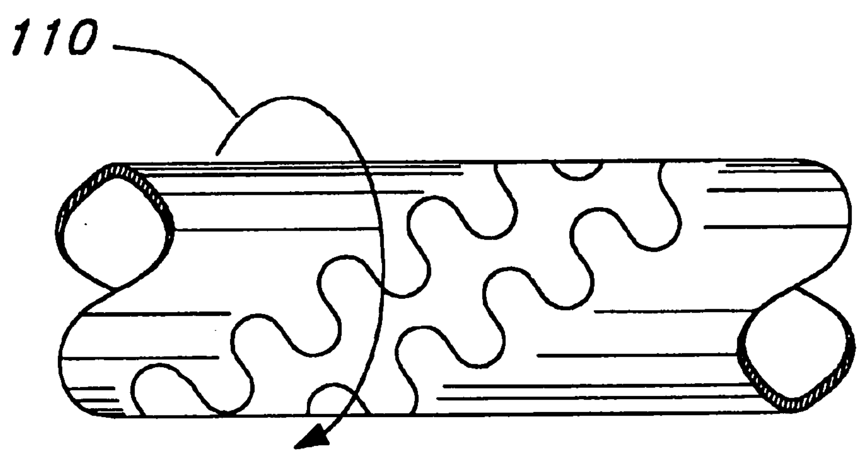

Fig. 7C

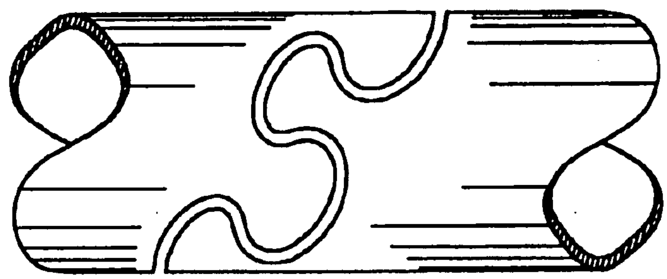

Fig.8

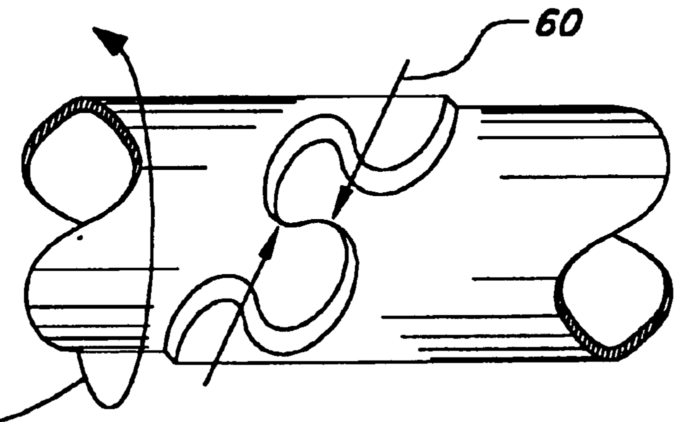

Fig.9

Fig.10

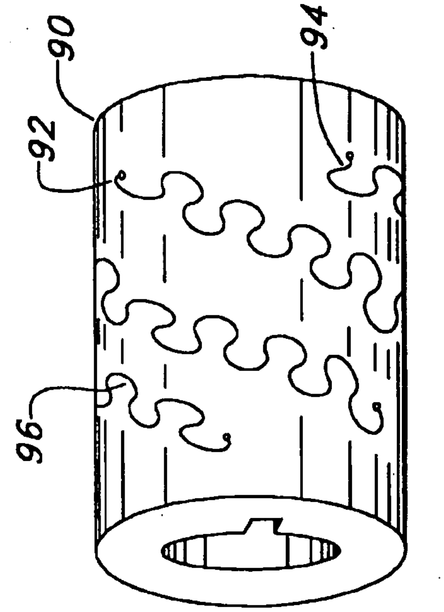

Fig. 11

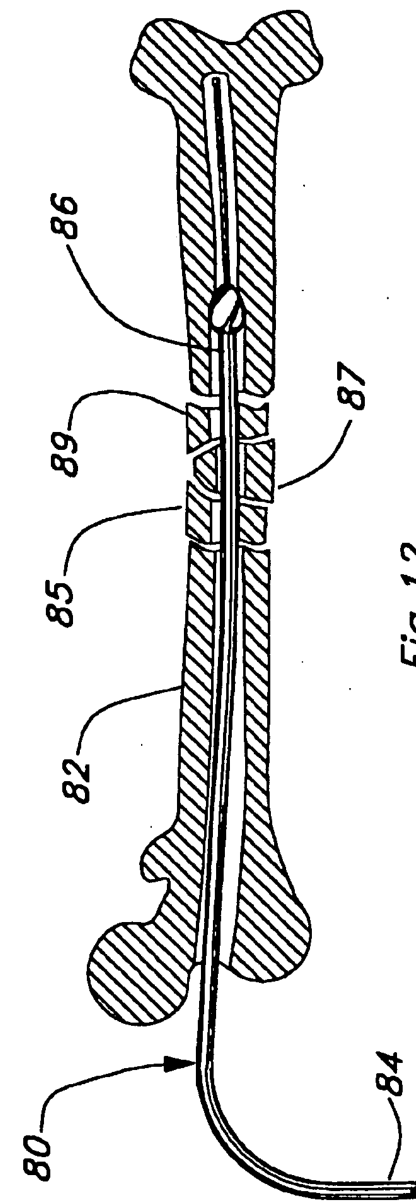

Fig. 12

FLEXIBLE SHAFT

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation in part of copending provisional patent application, Ser. No. 60/006,064 filed Oct. 23, 1995 and copending provisional application Ser. No., 60/001,475 filed Jul. 18, 1995, the subject matters of which are incorporated herein, by reference, as though recited in full.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to flexible shafts and couplings; specifically to an improved flexible shaft for the transmission of rotary motion and power around, over or under obstacles. The invention specifically includes an improved flexible shaft for the purpose of reaming the medullary canal of bones.

2. Brief Description of the Prior Art

Flexible shafts and couplings are used to transmit rotary power between a power source and a driven part when a straight, unobstructed path is unavailable. A flexible shaft generally consists of rotating shaft with end fittings for attachment to mating parts, typically a power source and the driven part, as depicted in FIG. 3 of U.S. Pat. No. 4,646,738, Suhner catalog at page 6, and the S. S. White Technologies Inc. catalog, page 4, (1994). A protective outer casing may be used to protect the shaft when necessary. Flexible shafts are used in numerous applications anywhere the transmission of rotary power is necessary and a straight unobstructed path is unavailable, as depicted in the S. S. White Technologies Inc. catalog, page 5 and Suhner at page 6. Flexible shafts have been used in children's toys to aerospace applications. Examples of the usage of flexible shafts have been presented in the articles "New Twists for Flexible Shafts" (Machine Design, Sep. 7, 1989), in particular pages as illustrated on pages 145 and 146, and "Flexible Shafts Make Obstacles Disappear" (Power Transmission Design, July, 1993), in particular FIG. 1. One example cited was a safety valve, located 30 ft. off the ground and not readily accessible, that had to be operated on a daily basis to remain operable, but was not exercised as regularly as required due to the difficulty in reaching it. With the installation of a flexible shaft from the valve to floor level, personnel were able to operate the valve regularly and verify its proper function. Flexible shafts are used on aircraft to raise and lower wing flaps, slats, and leading and trailing edges. Stainless steel flexible shafts allow surgeons greater maneuverability with bone cutting and shaping tools. Flexible shafts are also used extensively to compensate for less than perfect alignment between a driver and a driven component. The limitation for the use of flexible shafts are limitless and is only limited by the torque capabilities of the shaft.

The principle application of a flexible shaft is to transmit rotary motion and power in a curvilinear manner. Flexible shafts are used when there is little or no accurate alignment between the power source and the driven part; when the path between the power source and the driven part is blocked or is in an environment or position which would not allow the power source; for the connection or driving of components which have relative motions; and to dampen and absorb vibration both from the drive unit and the driven tool.

Heretofore, flexible shafts and couplings available for power transmission consisted of single or multiple wires wound over a central drive core or a hollow core, as illustrated in U.S. Pat. No. 5,108,411, FIG. 2, and as depicted in the Suhner publication, pages 15 and 16. The number of wires per layer and the number of layers will vary according to the application and requirements for either unidirectional or bidirectional torque power transmission. Typically wire wound flexible shafts are designed and manufactured to be operated in only one direction of rotation; either clockwise or counter clockwise, when viewed from the driving end. They are designed to maximize the torque carrying capabilities for the direction of rotation for which they were designed. The performance of a unidirectional shaft operated in the reverse direction is significantly less than the intended performance levels.

A specific application of flexible shafts is with flexible medullary canal reamers. Medullary canal reamers are used to enlarge the medullary canal of bones in preparation for the insertion of prosthetic components, such as a total hip prosthesis, the insertion of fracture reduction and fixation devices, such as intramedullary nails, performing an intramedullary osteotomy, the insertion of a plug to preclude bone cement from migrating while in its viscous state, stimulating bone growth, and for other purposes. Since the medullary canal is irregular in internal diameter and configuration from end to end it is preferred by the surgeon to enlarge the medullary canal to a more uniform diameter or to a diameter that will allow passage or insertion of the intended device. Because the shafts of long bones are bent or curved along their longitudinal axes, flexible shafts that can bend to follow this naturally curved path while transmitting the necessary torque required to cut the bone are necessary.

Should a straight, rigid, or inflexible shaft be used in the reaming process to enlarge the canal, there is considerable likelihood that the reamer will not follow the natural curvature of the bone, will not remove the desired amount of bone and will not produce a uniform internal diameter. In addition, should a straight, rigid reamer be used, there is a high degree of likelihood that the reamer will jam, cause excessive bone removal or penetrate the outer integrity of the bone. For this reason, medullary canals are almost always prepared with reamers having a flexible shaft. Flexible medullary reamers are of such design that utilizes a central bore intended to receive a long, small diameter guide rod or wire which is initially inserted into the medullary canal. The guide wire or rod establishes a track for the advancing reamer. However, the use of a flexible reamer does not preclude the problem of jamming or reamer stoppage when the cutting head of the reamer gets caught by the bony structure and does not turn. A jammed cutting head may be extremely difficult, if not impossible to dislodge or remove without further violation of the involved bone or breakage of the reaming device. The preferred method to dislodge the reamer would be to reverse the reamer. However, the design of the most widely used devices prevent the reversal of the reamer without destruction of the flexible shaft.

Heretofore, the flexible medullary shaft reamers available to the orthopedic surgeon are of three types: (i) a shaft with a plurality of parallel flexible elements or rods joined together at opposite ends by means of a welded of soldered connection, (ii) a shaft comprised of a spiral or helically wound metal wire(s) or strip(s), and (iii) a shaft comprised of a series of inter-engaged links, assembled over a guide rod.

The first distinct type of flexible medullary reamer (i) embodies a plurality of parallel, flexible elements joined

together at opposite ends. A disadvantage of this shaft occurs during usage as the reamer rotates causing the elements to become twisted and thereby to become more rigid and reduce the shaft's flexibility. Another disadvantage of said reamer is the shaft's tendency, as it rotates but is not yet fully within the confines of the medullary canal, to tear tissue from underlying structures as the individual elements are torsionally loaded and unloaded, thereby enlarging and contracting the spaces between the individual wires to trap uninvolved tissue and tearing them free. Another disadvantage of said flexible reamer occurs during insertion of the reamer over the guide rod. The central bore is intended to receive the small diameter guide rod. Except at its respective ends, this reamer lacks a well defined and bordered central bore. Therefore it is difficult to prevent the guide rod from exiting the reamer in the area of the free standing elements during the insertion of the guide wire. A further disadvantage of this flexible shaft is the inefficient transfer of energy from the power source to the cutting head which is caused by the twisting and wrapping together of the individual elements as the reamer is rotated. Another disadvantage of this type of reamer is that it is extremely noisy during operation due to the multiple elements hitting one another during the rotation.

The second distinct type of flexible medullary reamer (ii) consists of spiral or helically wound metal wires or strips. This is the most widely used flexible shaft for intramedullary reaming. The major disadvantage of this reamer design is that it can only be operated in the forward mode of operation. If the cutter becomes jammed and the surgeon reverses the reamer to dislodge the cutter or to facilitate removal, the shaft unwinds, thus rendering the reamer permanently deformed, unusable, and unrepairable. A further disadvantage of this medullary reamer is that the torsional load to which it is subjected when in use results in poor power transfer and varying degrees of distortion of said shaft. If the power source providing the rotational energy to the reamer is great enough, said coils may tighten sufficiently to adversely affect the structural integrity of the shaft and cause the shaft to permanently deform into a helical shape. A further disadvantage of this type of reamer is the inability to clean the shaft and the cavities within the helically wound strips of surgical debris after the operation for the prevention of cross contamination between patients. If infectious blood or body fluids infiltrates the mechanism of the device, it is extremely difficult to remove and clean.

The third distinct type of flexible shaft (iii) consists of a series of inter-engaged links assembled over a guide wire. A distinct disadvantage of this design is during usage and interchanging the cutting head. The current usage of this design dictates that the links are held together by a longitudinal guide wire over which the linkages are assembled. In order to change the cutting head, a flexible tube must be inserted through the central bore of the linkages, and the assembled links must be taken off the centralizing guide wire. In the process linkages frequently become unassembled and require the surgeon to reassemble the linkages.

U.S. Pat. No. 5,488,761 to Leone, shows prior art spiral wound flexible shafts using a single shaft and a pair of reverse wound shafts. The patent also discloses materials of construction for the shaft and a mechanism for cleaning the slot, after it is cutting. Alternate cutting technologies are also disclosed.

The prior art is depicted in Matthews, U.S. Pat. No. 4,706,659 which show two modifications of prior art devices, in FIGS. 1 and 2. The device of Matthews is loosely related to the present invention in that it is a mechanism for providing a flexible connecting shaft for an intramedullary reamer. While the proposed solution to the problem is different from that of the present invention, the patent discloses the importance of a flexible connection and discloses reamer structures. The disclosure of Matthews U.S. Pat. No. 4,706,659 is incorporated by reference herein, as though recited in full.

U.S. Pat. No. 4,751,922 (DiPietropolo) also shows the importance of flexible medullary reamers and explains some of the prior art problems. The patent also discloses the use of a hollow core **2**, for receiving a guide pin.

U.S. Pat. No. 5,122,134 (Borzone et al) is incorporated by reference as though recited in full and is noted to disclose in FIG. 5, the use of a guide pin **55**.

FIG. 1 of Zublin, U.S. Pat. No. 2,515,365 illustrates a flexible drill pipe for use in the drilling of well bores. Additional Zublin patents include U.S. Pat. Nos. 2,515,366, 2,382,933, 2,336,338 and 2,344,277. The drill pipe is a helically slotted flexible drill pipe having a slot varying from 3/32 of an inch (0.0938") to 5/32 of an inch (0.1563") in width and having a pitch of the spiral of about nine inches for a four and one-half inch diameter drill pipe (helix angle of 32.48 deg). Zublin indicates that the described flexible resilient drill pipe has the capacity to bend into a curve of an eighteen foot diameter utilizing a repeating "dovetail" pattern of over six cycles per revolution, for use with four and one half inch diameter drill pipe. In the instant invention, it has been found that shafts of one inch or less require the use of a helix angle of approximately one half that described by Zublin and that the number of repeating cycles of the interlocking pattern is less than the shown six cycles per revolution. For the smallest of flexible shafts describe, the use of about two pattern repetitions (cycles) per spiral revolution is more appropriate.

Accordingly it is an object of this invention to provide a flexible shaft which will flex, bend or curve to follow the natural intramedullary canal of the bone while transmitting reaming torque.

It is a further object of this invention to provide a flexible shaft which may be operated both in the forward and reverse directions therefore with equal effectiveness.

It is a further object of this invention to provide a flexible shaft which will have considerable rotational or torsional stiffness so that it will not store and then irregularly release rotational energy.

It is a further object of the invention to provide a flexible shaft which will be of a single one unit which does not have to be assembled from multiple units.

It is another object of this invention to provide a flexible shaft which will flex, bend or curve while transmitting torque.

It is a further object of this invention to provide a flexible shaft which may be operated both in the clockwise and counter clockwise directions therefore with equal effectiveness.

It is a further object of this invention to provide a flexible shaft which will have considerable rotational or torsional stiffness so that it will not store and then irregularly release rotational energy.

It is a further object of the invention to provide a flexible shaft which will be of a single unit which does not have to be assembled from multiple units.

It is a further object of the invention to provide a flexible coupling which will flex, bend or curve while transmitting torque.

These and other objects, features, advantages and aspects of the present invention will be better understood with

reference to the following detailed description of the preferred embodiments when read in conjunction with the appended drawing figures.

SUMMARY OF THE INVENTION

The present invention overcomes the deficiencies and problems evident in the prior art as described herein above by combining the following features into an integral, longitudinally flexible and torsionally inflexible shaft.

A flexible shaft is provided for the transmission of rotary power from a drive power unit to a driven unit. The driven unit can be a drill bit, a surgical reamer, a pump, or any similar device. The flexible shaft is an elongated tubular member of substantial wall thickness. The diameter of the shaft is preferably in the range from about 0.15 inch to about 4.00 inch. The ratio of the diameter of the inside diameter of the shaft to the outside diameter of the shaft is advantageously in the range from about 1:1.2 to about 1:3, and preferably is in the range from about 1:1.3 to about 1:4. The thinner the wall of the shaft, the more critical is the configuration of the slot.

Advantageously, the slot is cut at an angle normal to the shaft using a computer controlled cutting technique such as laser cutting, water jet cutting, milling or other means. Additionally, this slot may be cut at an angle to the normal so as to provide an undercut slot, preferably the angle is in the range from about 30 to about 45 degress from the normal.

A slot of substantial length and width extends in a generally helical path, either continuously or intermittently, around and along the tubular member. The slot follows a serpentine path along the helical path generally around and along the tubular member, corresponding generally to the form of a signal wave on a carrier wave, that is, an amplitude modulated carrier wave.

A plurality of slots, can be employed thereby increasing the flexibility of the shaft, relative to a shaft having a single slot of identical pattern. The serpentine path forms a plurality of teeth and complimentary recesses on opposite sides of the slot. The slot has sufficient width to form an unbound joint permitting limited movement in any direction between the teeth and the recesses, thereby providing limited flexibility in all directions upon application of tensile, compressive, and/or torsion forces to said shaft.

The flexible shaft can have different degrees of flexibility along the length of said shaft. The varied flexibility can be achieved by having the pitch of the helical slot vary along the length of the shaft. The varied flexibility corresponds to the variation in the pitch of the helical slot. The helical path can have a helix angle in the range of about 10 degrees to about 45 degrees, and the helix angle can be varied along the length of the shaft to produce correspondingly varied flexibility. Alternatively, the width of the helical slot can vary along the length of the shaft to provide the varied flexibility. Advantageously, the width of the slot is preferably in the range from about 0.005 inch to 0.075 inch. Preferably the width of the slot is in the range from about 0.01 to about 0.05 inch. The rigidity of the flexible shaft can be achieved through the design of the slot pattern, thereby enabling the use of thinner walls than would otherwise be require to produce equivalent rigidity. In a preferred embodiment, the ratio of the amplitude of the serpentine path to the pitch of the slot is in the range from greater than 0.1 to about 0.5.

The slot can be filled with a resilient material, partially or entirely along the path of the slot. The resilient material can be an elastomer compound which can be of sufficient thickness to fill the slot and to encapsulate the entire shaft thus forming an elastomer enclosed member. The elastomer can be a resilient material such as a urethane or a silicone compound.

In a preferred embodiment the driven unit is a medullary canal reamer, for use in reaming the medullary canal of bones. In this application, the foregoing slot patterns and shaft dimensions, are particularly critical.

Preferably, the flexible shaft, is formed by laser cutting an elongated tubular member of substantial wall thickness, to form the slot around and along the tubular member. The serpentine path can form of a generally sinusoidal wave superimposed on a helical wave.

Preferably, the sinusoidal wave forms dovetail-like teeth, which have a narrow base region and an anterior region which is wider than the base region. Thus, adjacent teeth interlock. The teeth can have a configuration as illustrated in U.S. Pat. No. 4,328,839, the disclosure of which is incorporated herein by reference, as though recited in detail.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features, advantages and aspects of the present invention will be better understood with reference to the following detailed description of the preferred embodiments when read in conjunction with the appended drawing figures.

FIG. 1 is a schematic representation of a flexible shaft of the present invention;

FIG. 2 is a schematic representation of the spiral slit of FIG. 1, showing coated and uncoated regions;

FIGS. 3 and 4 are schematic illustrations showing the angle of the slot;

FIG. 5 is a schematic representation of a flexible cable with a resilient filler in a portion of the slot;

FIGS. 6A–6K show schematic representations of additional spiral slit patterns;

FIGS. 7A–7C are schematic side views showing spiral slits having various numbers of cycles per revolution, that is, differents pitches;

FIG. 8 is a fragmentary side view of the embodiment of FIG. 7, showing the gap formed by the slit;

FIG. 9 is a fragmentary side view of the embodiment of FIG. 8, showing a section of the device of the present invention after being torqued in the clockwise direction;

FIG. 10 is a fragmentary side view of the embodiment of FIG. 8, showing a section of the device of the present invention after being torqued in the counterclockwise direction;

FIG. 11 is a perspective view of a flexible coupling using the spiral slit of the present inventio and showing a plurality of spirals slots; and

FIG. 12 is a schematic and cut away view of the shaft employed in reamering a medullary canal of a femur.

DEFINITIONS AND TERMS

The term slot as used herein, is defined in the American Heritage Dictionary, 3rd Edition, Copyright 1994, as follows:

The terms slit and slot are used interchangeably, consistent with their definitions, as follows:

slot n.

1. A narrow opening; a groove or slit: a slot for coins in a vending machine; a mail slot.

2. A gap between a main and an auxiliary airfoil to provide space for airflow and facilitate the smooth passage of air over the wing.

The term pitch as used herein, is defined in the American Heritage Dictionary, 3rd Edition, Copyright 1994, as follows:

pitch—n.

1. The distance traveled by a machine screw in one revolution.

2. The distance between two corresponding points on adjacent screw threads or gear teeth.

The term helix angle, angle ψ in FIG. **1**, as used herein, shall define the angle formed between the plane perpendicular to the longitudinal axis of the shaft and the helical path of the spiral along the shaft. The term helix angle can also be defined mathematically as the arc tangent of the pitch of the helix divided by the circumference of the shaft.

The terms used herein are intended to have their customary meanings as set forth in the American Heritage Dictionary, 3rd Edition, Copyright 1994.

Cycle-1. An interval of time during which a characteristic, often regularly repeated event or sequence of events occurs: Sunspots increase and decrease in intensity in an 11-year cycle.

2.a. A single complete execution of a periodically repeated phenomenon: A year constitutes a cycle of the seasons.

2b. A periodically repeated sequence of events: cycle includes two halves of the sine-wave like undulation of the slot path.

Spiral 1a.

A curve on a plane that winds around a fixed center point at a continuously increasing or decreasing distance from the point.

1b. A three-dimensional curve that turns around an axis at a constant or continuously varying distance while moving parallel to the axis; a helix.

1c. Something having the form of such a curve: a spiral of black smoke.

2. Printing. A spiral binding.

3. Course or flight path of an object rotating on its longitudinal axis.

4. A continuously accelerating increase or decrease: the wage-price spiral.

Spiral (adj.)

1. Of or resembling a spiral.

2. Circling around a center at a continuously increasing or decreasing distance.

3. Coiling around an axis in a constantly changing series of planes; helical.

The term amplitude, as used herein the maximum absolute value of the periodically varying quantity of the slot **30**.

The spiral is more explicitly a helix-like, in that it is a three-dimensional curve that lies on a cylinder, so that its angle to a plane perpendicular to the axis is constant. However, along the length of the shaft, the helix angle may vary so as to impart changes in flexibility to the overall shaft. Using an electronics analogy, the helix can be viewed as a carrier wave with the slot following the path of the modulation of the carrier wave. The teeth or interlocking regions of the cycle, form a ratchet-like structure, in that one set of teeth engage the other set of sloping teeth, permitting motion in one direction only.

The term frequency, the number of times a specified phenomenon occurs within a specified interval, as stated in the American Heritage Dictionary, 3rd Edition, Copyright 1994:

Frequency.

1a. Number of repetitions of a complete sequence of values of a periodic function per unit variation of an independent variable.

1b. Number of complete cycles of a periodic process occurring per unit time.

1c. Number of repetitions per unit time of a complete waveform, as of an electric current.

The number of times the cycles form a repetitive pattern in one unit of length is the frequency of the slot pattern.

The number of cycles "C" of the slot undulations superimposed upon the helical path which are present in one revolution around the shaft, is referred to as the cycles per revolution.

As used herein the term serpentine refers to the undulations of the cut in any geometric configuration whether it is dovetailed, mating or winding fashion.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The shaft of the device of the present invention, indicated generally as **10** as illustrated in FIG. **1** includes an end **14** provided for attachment to a drive means such as an electric or gas driven motor. At the other end **13**, of the device **10** includes a connection member **11** providing for attachment to a driven part **15** such as a tool, gearbox, or connecting shaft. The device **10** includes a longitudinal bore **20** spanning from the end **13** to the end **14** thus providing a channel for passage of wires and other instrumentation, as well known in the art and discussed above. The device **10** includes a slot **32** cut through the wall **22** of the shaft **10**, so as to form a serpentine path which extends generally along the path of a spiral around the shaft **10**, as shown in Zublin, U.S. Pat. No. 2,515,365, as dotted line 20, FIG. 1.

When employing the flexible shaft **10** for the transmission of power from the driven end **14** to the driven part **15**, the serpentine slot **32** along the spiral path permits the device **10** to bend along the longitudinal axis of the device **10**. The dovetail configuration of the serpentine slot **32** is composed of teeth **36** and **38**. Teeth **36** and **38** will effectively interlock the sections of the dovetail **34** above and below the teeth **36** and **38** and will thereby transmit torque.

Where the device is to be used as a flexible shaft for power transmission, the shaft typically has a diameter less than an inch but may be larger depending upon the specific application. The slot characteristics shown in U.S. Pat. No. 2,515,365 cannot be applied to this application. A one inch or less shaft must have a lower helix angle of the helical path, a higher spiral frequency and fewer cycles of slot undulations about the helical path to provide the required combination of structural strength and flexibility.

Advantageously, the slot is cut perpendicular to a plane tangent to the outer surface of the shaft as shown in FIG. **3**. Alternatively, the slot can be cut at some angle to the longitudinal axis of the shaft and/or the plane tangent to the outer surface, as shown in FIG. **4**. The angle can be in the range from zero (perpendicular) to about 75 degrees thereby forming an undercut. Preferably the angle if not perpendicular, is in the range from about 30 to 45 degrees from the perpendicular. The undercut can be formed by cutting offset from the radius, or offsetting from a plane tangential to the surface of the shaft at the slot.

Additionally, in a preferred embodiment, the body of the shaft has a high level of flexibility to facilitate movement around, over or under an obstacle. The preferred embodiment can be constructed in such a manner to provided

varying degrees or segments of customized flexibility. Variations in flexibility can most readily be achieved by varying the length of the region which is cut with the spiral slots as well as varying the angle of the slot relative to the long axis of the shaft. Thus, where high flexibility is required a longer length of spiral slot can be used and a greater region length cut. Where less flexibility is required, a short slot length can be used. Customization enhances the ability to drive the shaft in a straight line where required, to negotiate around, over or under obstacles and/or to be driven by a rotary power source whose axis is substantially out of line with the axis of the driven part.

Whereas FIG. 1 of Zublin, 2,515,365 illustrates over six cycles per revolution, for use with four and one half inch diameter drill pipe, in the instant invention, it has been found that shafts of one inch or less requires the use of one to four cycles per revolution depending upon the shaft diameter. Thus, the change in shaft diameter does not result in a proportional change in size of the slot pattern. It has been found that the lower number of helical cycles per revolution produces greater resistance to fracture under torque while providing a less flexible shaft. Most preferably, flexible shafts have a helix angle of less than twenty degrees, in order to produce the required balance between flexibility and structural strength. The range is preferably from about 15 to 20 degrees resulting in a pitch equal to the diameter of the shaft. While the use of a small helix angle, resulting in a higher number of revolutions per unit shaft length, is not preferred unless a very flexible shaft is desired, fewer revolutions per unit length can be used where less flexibility is required. For example, in the varying flexibility flexible shaft, the number of revolutions can be reduced in the relatively rigid regions, as compared to the higher flexibility regions. As shown in FIG. 2, the flexible shaft indicated generally as **100** has the advantage of providing an ability to be routed around, over or under an obstacle, connect to a moving obstacle, provide connection with an unaligned component or to a part in a harsh environment requiring power. The use of a highly flexible shaft **86** permits for ease of guiding the required power to be transmitted to the required part.

The advantage of such a variable flexible shaft, is for a control shaft that must be snaked around different sized obstacles. In sections requiring a smaller radius of curvature, the disclosed shaft can be manufactured for highest flexibility. When variable flexibility is required, the shaft can be cut in restricted areas, or regions, with parts of the shaft remaining uncut. This produces a straight, non-flexible region. The larger the radius of curvature, the less flexible the shaft. The pitch, pattern and length of each region cut can vary within parts of the shaft to provide varying flexibility.

FIG. 1 shows the helix angle, ψ, of the spiral. The smaller the angle, the larger the number of revolutions "R" of the helical path, per inch and the greater the flexibility of the shaft.

A variety of slot patterns are illustrated in FIG. 6A–K. The patterns are representative of patterns which can be used and are not intended to be all inclusive. As illustrated in FIG. 6A, the pattern has a cycle length C, which includes a neck region NA. The wider the neck region the greater the strength of the connector, that is, the greater the torsional forces which the flexible shaft can transmit. The ability of the device to interlock is dependent in part upon the amount of overlap or dovetailing, indicated as DTA for FIG. 6A and DTB for FIG. 6B. The pattern of 6C, does not provide dovetailing, and requires a helix angle which is relatively small. FIG. 6D illustrates a segmented, elliptical dovetail configuration with CD indicating the cycle of repetition. In FIG. 6E the ellipse has been rounded out to form a circular dovetail cut with CE indicating the repetitive cycle and the cut pattern of FIG. 6F is a dovetailed frustum. The pattern of FIG. 6G is a sine wave pattern forming the helical path. FIG. 6H is an interrupted spiral in which the slot follows the helical path, deviates from the original angle for a given distance, and then resumes the original or another helix angle. FIG. 6I is the same pattern as FIG. 6H, however in FIG. 6H there are two lead cuts while in FIG. 6I there is a single lead cut. FIGS. 6J and 6K show two dimensions of the same pattern having multiple leads.

As shown in FIG. 7C, rotation in the direction of arrow **110** can open the spiral. The steeper angles of FIGS. 7B and 7C provide progressively greater resistance to opening, even without the dovetailing effect being present. It should be noted that in certain patterns, it is preferred to provide an odd number of cycles per revolution, as shown in FIGS. 7A, 7B and 7C. In this manner the peak point of the cycle **41**, is out of phase with the peak point **42** of the next revolution. In these embodiments when the two points are in phase, the amount of material between the two points is so small as to provide an adequate structural strength. Obviously, the use of a steep helix angle, that is, a very low number of cycles per revolution can be used to provide adequate space between the peak points **41** and **42**.

The flexible shaft can be produced by any convenient means. Computer controlled milling or cutting, wire electrical discharge machining, water jet machining, spark erosion machining, and most preferably laser cutting is most conveniently used to produce the desired pattern. The advantages of computer controlled laser cutting are the infinite variety of slot patterns which can be produced, the ability to change the helix angle at any point along the shaft, the variations with respect to slot width, and the overall precision afforded, as compared to conventional cutting mechanisms. The combination of laser cutting with the slot patterns of this inventions, can produce customized shafts having not only a predetermined flexibility, but also predetermined variations in flexibility, while providing substantially uniform characteristics with counterclockwise and clockwise rotation.

The effect of the rotational forces on the flexible shaft is further shown in FIGS. 8, 9 and 10. Rotation in the direction of arrow **62** applies a force in the direction of arrow **62**, at the neck region, making contact at point **60**. Conversely, rotation in the direction of arrow **70** applies a force in the direction of arrow **70** at the neck region, making contact at point **72**.

FIG. **11** shows the design of a flexible connector **90** which can be inserted between, for example, between a rotary power supply and an inflexible or moderately flexible shaft. The flexible connector can be used to provide power transmission between misaligned parts as previously described. In this embodiment, advantageously, a plurality of slots **92**, **94** and **96** can be used, as shown in FIG. **11**.

FIG. **2** shows the design of a flexible shaft or connector **100** in which an elastomer or otherwise flexible material is interposed within the slot **102** to further enhance the flexibility of the shaft and to alter the torsional response or stiffness of the member. The elastomer can be used as a shock absorbing or cushioning member. To facilitate manufacture, to provide protection of the tubular member, to provide a fluid conduit or for other reasons, the elastomer can encapsulate the entire shaft or coupler, thus forming a tubular construction **104**.

In a preferred embodiment of the invention the flexible shaft is to be used as a flexible shaft for reaming the medullary canal of bones, the shaft must have a diameter less than that of the reamer which typically has a cutting diameter of about two tenths of an inch up to less than three quarters of an inch. The spiral pattern shown in U.S. Pat. No. 2,515,365 cannot be applied to this application. The three quarter inch or less shaft must have a higher spiral frequency (lower helix angle) and fewer superimposed slot cycles to provide the required combination of structural strength and flexibility. As show in FIG. **12**, during the reaming of the medullary canal of the femur it is preferred that the shaft be able to flex, up to about 45 degrees. The flexible shaft indicated generally as **80** has the advantage of providing an ability to ream the medullary canal of the femur **82** with the driven end **84** of the shaft at roughly a right angle to the axis of the femur The use of a highly flexible reamer end **86** permits for ease of guiding the reamer through the bone fragments **85**, **87** and **89**.

What is claimed is:

1. A flexible shaft comprising an elongated tubular member of substantial wall thickness, said tubular member having:
   (i) a first end;
   (ii) a second end; and
   (iii) a center section, said center section being positioned between said first end and said second end, said center section having a slot extending in a generally helical serpentine path around and along said tubular member center section, said helical path having from about 1 to about 4 cycles per revolution, said slot having a substantial length and width of up to about 0.075 of an inch, said tubular member having a diameter in the range from about 0.15 to four inches, a helical angle of up to about 20 degrees, and a ratio of amplitude of said serpentine path to pitch in the range from greater than 0.1 to 0.5.

2. A flexible shaft comprising an elongated tubular member of substantial wall thickness, said tubular member having:
   (i) a first end;
   (ii) a second end; and
   (iii) a center section, said center section being positioned between said first end and said second end, said center section having a slot extending in a generally helical serpentine path around and along said tubular member center section, said slot having a substantial length and width said tubular member having a diameter in the range from about 0.15 to four inches and said helical path having from about 1 to about 4 cycles per revolution.

3. The flexible shaft of claim **2**, further comprising, a slot width of up to about five thirty seconds of an inch, a ratio of amplitude of said serpentine path to pitch in the range from greater than 0.1 to 0.5 and a helical angle of up to about 20 degrees.

4. The flexible shaft of claim **2**, wherein said slot is under cut at an angle to a radial line or a plane tangential to the surface of the shaft at the slot, said angle being at least about 15 degrees from the perpendicular.

5. A flexible shaft comprising an elongated tubular member of substantial wall thickness, said tubular member having:
   (i) a first end;
   (ii) a second end; and
   (iii) a center section, said center section being positioned between said first end and said second end, said center section having a slot extending in a generally helical serpentine path around and along said tubular member center section, said slot having a substantial length and width, said tubular member having a diameter in the range from about 0.15 to four inches and a ratio of amplitude of said serpentine path to pitch in the range from greater than 0.1 to 0.5.

6. The flexible shaft of claim **5**, further comprising, a slot width of up to about 0.075 of an inch, a helical angle of up to about 20 degrees, and said helical path having from about 1 to about 4 cycles per revolution.

7. A flexible shaft comprising an elongated tubular member of substantial wall thickness, said tubular member having:
   (i) a first end;
   (ii) a second end; and
   (iii) a center section, said center section being positioned between said first end and said second end, said center section having a slot extending in a generally helical serpentine path around and along said tubular member center section, said slot having a substantial length and width, said tubular member having a diameter in the range from about 0.15 to four inches and the ratio of the diameter of the inside diameter of said shaft to the outside diameter of said shaft is in the range from about 1:1.2 to about 1:3.

8. A flexible shaft comprising an elongated tubular member of substantial wall thickness, said tubular member having:
   (i) a first end;
   (ii) a second end; and
   (iii) a center section, said center section being positioned between said first end and said second end, said center section having a slot extending in a generally helical serpentine path around and along said tubular member center section, said slot having a substantial length and width and said helical path having from about 1 to about 4 cycles per revolution.

9. A flexible shaft comprising an elongated tubular member of substantial wall thickness, said tubular member having:
   (i) a first connecting section at a first end of said tubular member;
   (ii) a second connecting section at a second end of said tubular member; and
   (iv) a center section, said center section having a plurality of slots along a serpentine path, said plurality of slots having a substantial length and width extending within a region around said tubular member, wherein at least one of said plurality of slots follows a generally helical path around and along said tubular member.

10. A flexible shaft comprising an elongated tubular member of substantial wall thickness, said tubular member having:
   (i) a first connecting section at a first end of said tubular member;
   (ii) a second connecting section at a second end of said tubular member; and
   (iii) a center section, said center section having a slot along a serpentine path, said slot having a substantial length and width extending in a generally helical path within a region around and along the tubular member and being at least partially filled with a resilient material;

   wherein said serpentine path forms a plurality of teeth and complimentary recesses on opposite sides of said slot,

said slot having sufficient width to form an unbound joint, said slot width and serpentine path permitting limited movement in all directions between the teeth and the recesses, thereby providing limited flexibility in all directions upon application of tensile, compressive, or torsion forces to said shaft.

11. The flexible shaft of claim **10**, wherein said resilient material is an elastomer compound of sufficient thickness to encapsulate substantially the entire shaft thus forming an enclosed member.

12. The flexible shaft of claim **11**, wherein said center section slot is a plurality of slots, at least two of said plurality of slots following a serpentine path around and along said tubular member.

13. The flexible shaft of claim **10**, wherein said center section slot is a plurality of slots, wherein at least two of said plurality of slots follow a serpentine path around and along the tubular member.

14. The flexible shaft of claim **10**, wherein the ratio of the diameter of the inside diameter of said shaft to the outside diameter of said shaft is in the range from about 1:1.2 to about 1:3, the slot width is in the range from about 0.005 inch to 0.075 inch, in the ratio of the amplitude of said serpentine path to the pitch of said slot is in the range from greater than 0.1 to about 0.5, said helical path has a helix angle in the range of about 10 degrees to about 20 degrees, said shaft has a diameter in the range from about 0.15 inch to about 4.00 inch.

15. The flexible shaft of claim **10**, wherein said slot is under cut at an angle to a radial line or a plane tangential to the surface of the shaft at the slot, said angle being at least about 15 degrees from the perpendicular.

16. The flexible shaft of claim **10**, further comprising a plurality of slots, wherein at least one of said plurality of slots starts on a first plane perpendicular to said tubular member's long axis and at least another of said plurality of slots starts on a sequential plane perpendicular to said tubular member's long axis.

17. A flexible shaft comprising an elongated tubular member of substantial wall thickness, said tubular member having:

(i) a first connecting section at a first end of said tubular member;

(ii) a second connecting section at a second end of said tubular member; and

(iii) a center section, said center section having a slot along a serpentine path, said slot having a substantial length and width extending in a generally helical path within a region around and along the tubular member, said center section being covered with a resilient elastomer material of sufficient thickness to encapsulate substantially the entire shaft to form an enclosed member,

wherein said serpentine path forms a plurality of teeth and complimentary recesses on opposite sides of said slot, said slot having sufficient width form an unbound joint, said slot width and serpentine path permitting limited movement in all direction between the teeth and the recesses, thereby providing limited flexibility in all directions upon application of tensile, compressive, or torsion forces to said shaft.

18. The flexible shaft of claim **17**, wherein said center section slot is a plurality of slots, wherein at least two of said plurality of slots follow a serpentine path around and along the tubular member.

19. The flexible shaft of claim **17**, wherein the ratio of the diameter of the inside diameter of said shaft to the outside diameter of said shaft is in the range from about 1:1.2 to about 1:3, the slot width is in the range from about 0.005 inch to 0.075 inch, in the ratio of the amplitude of said serpentine path to the pitch of said slot is in the range from greater than 0.1 to about 0.5, said helical path has a helix angle in the range of about 10 degrees to about 20 degrees, said shaft has a diameter in the range from about 0.15 inch to about 4.00 inch.

20. The flexible shaft of claim **17**, wherein said slot is under cut at an angle to a radial line or a plane tangential to the surface of the shaft at the slot, said angle being at least about 15 degrees from the perpendicular.

21. The flexible shaft of claim **17**, wherein at least one of said plurality of slots starts on a first plane perpendicular to said tubular member's long axis and at least another of said plurality of slots starts on a sequential plane perpendicular to said tubular member's long axis.

* * * * *

US005549613A

United States Patent [19]

Goble et al.

[11] Patent Number: 5,549,613

[45] Date of Patent: Aug. 27, 1996

[54] **MODULAR SURGICAL DRILL**

[75] Inventors: **E. Marlowe Goble**; **David P. Luman**, both of Logan, Utah; **Harold M. Martins**, Newton, Mass.

[73] Assignee: **Mitek Surgical Products, Inc.**, Westwood, Mass.

[21] Appl. No.: **122,202**

[22] Filed: **Sep. 15, 1993**

[51] **Int. Cl.**^{6} **A61B 17/56**

[52] **U.S. Cl.** **606/80**; 606/180; 408/231; 408/713

[58] **Field of Search** 606/80, 81, 79, 606/84, 85, 86, 88, 96, 98, 102, 180; 433/165; 408/203.5, 204, 226, 227, 229, 231, 232, 233, 713, 57, 59

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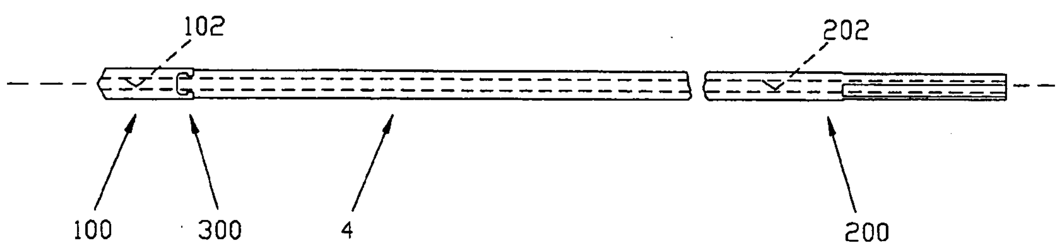
Primary Examiner—Guy Tucker
Attorney, Agent, or Firm—Pandiscio & Pandiscio

[57] **ABSTRACT**

A modular surgical drill in the form of a rigid drill shaft and a drill bit which are connected together at the rear end of the drill bit and the forward end of the drill shaft by a tongue-and-groove arrangement. Each of the shaft and drill bit are provided with through bores extending centrally through their entire length. These bores become aligned upon assembly of the drill bit and shaft. The modular drill is intended to be employed with a guidewire for drilling holes into bone. The assembled drill bit and shaft are placed on the guidewire and moved down such guidewire into contact with the bone, whereupon a tunnel may be formed into the bone by rotating and advancing the drill bit along the guidewire. The dimensions of the bore and guidewire are so selected as to prevent the drill bit and drill shaft from moving relative to one another once they are assembled and mounted upon the guidewire.

13 Claims, 19 Drawing Sheets



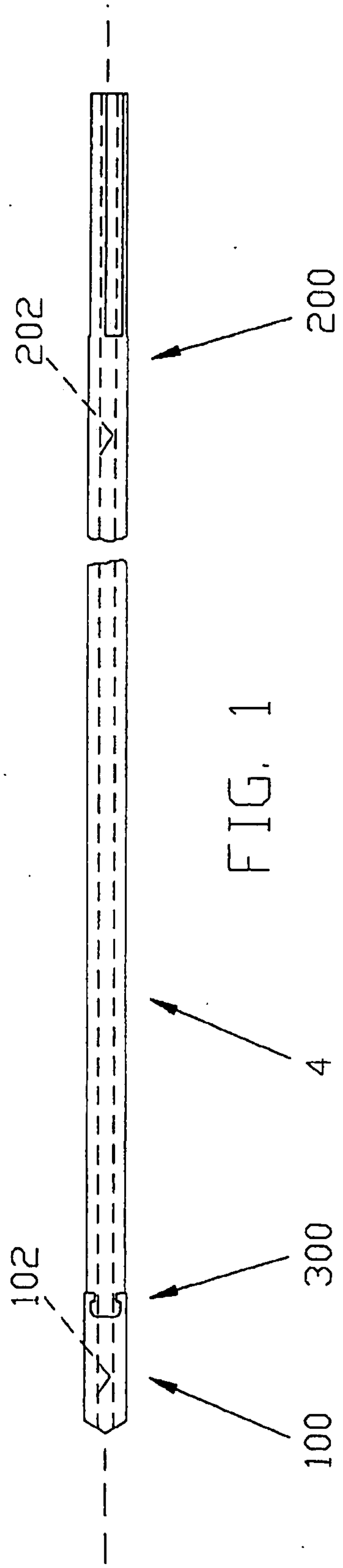


FIG. 1

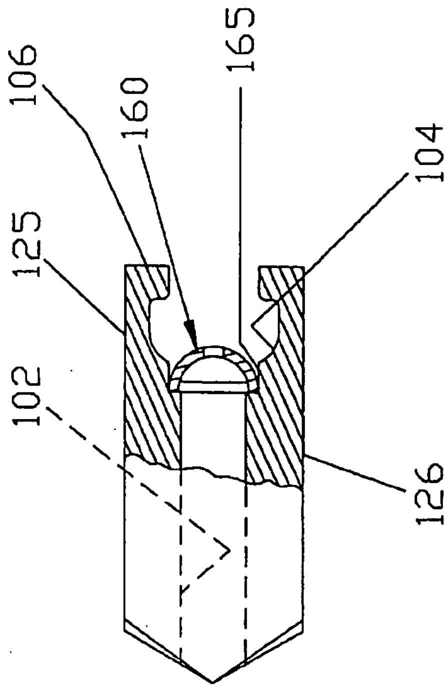


FIG. 2A

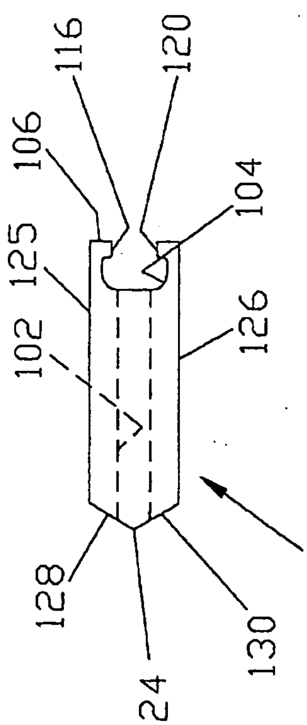


FIG. 2

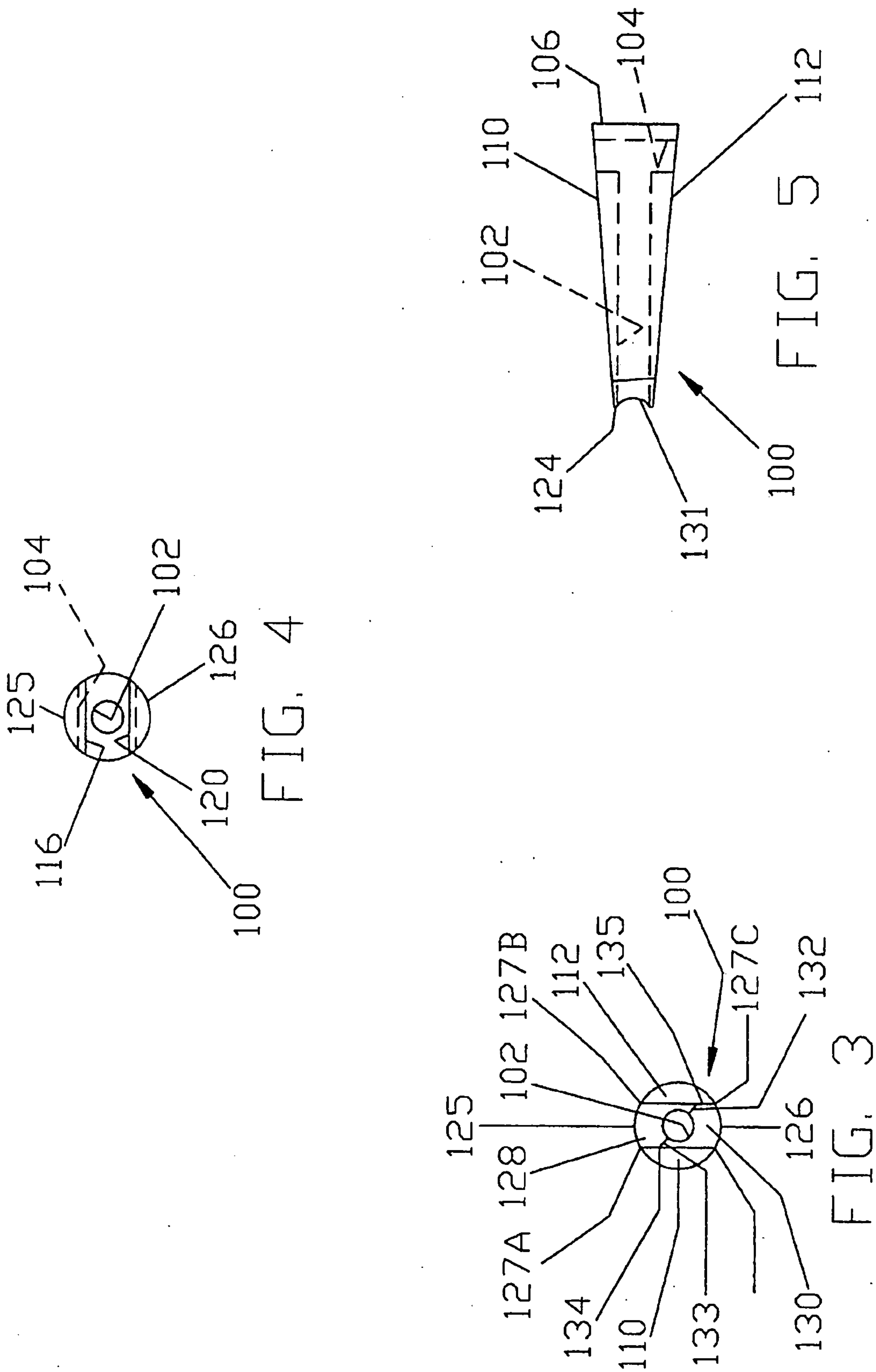


FIG. 5

FIG. 4

FIG. 3

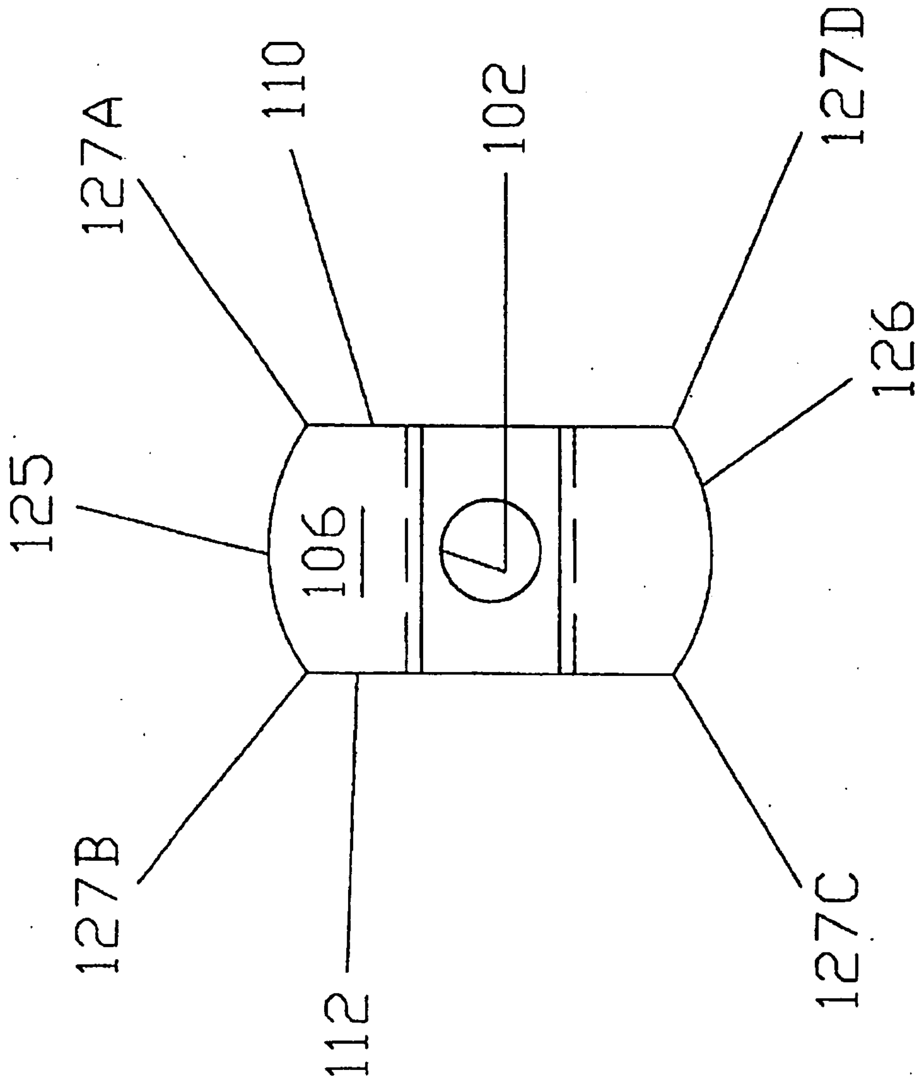


FIG. 4A

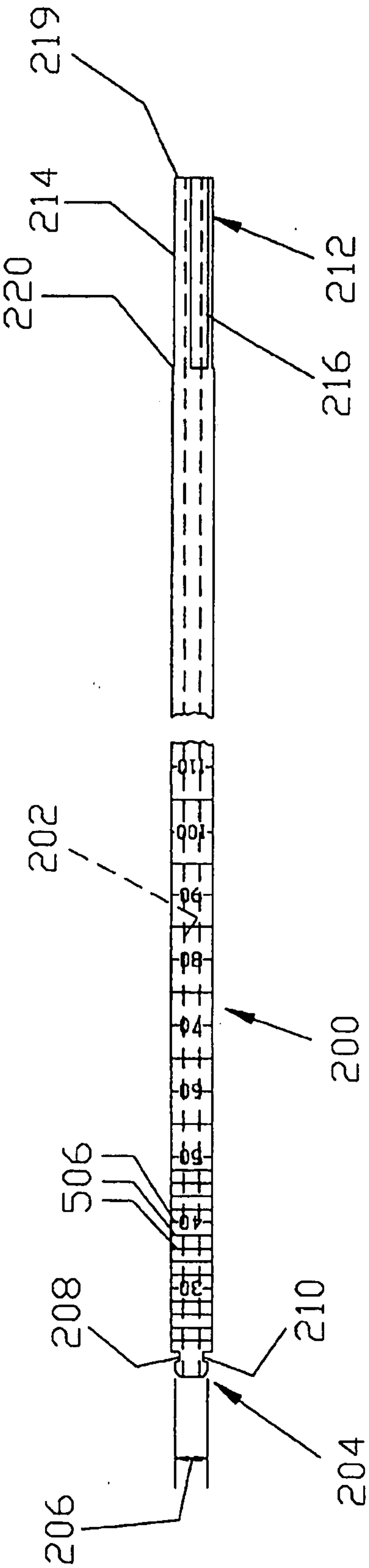


FIG. 6

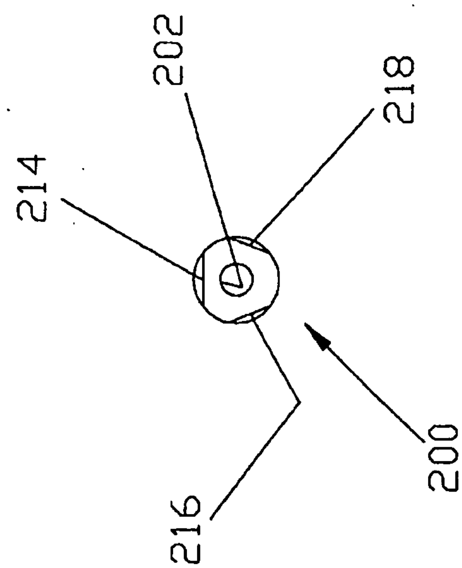


FIG. 8

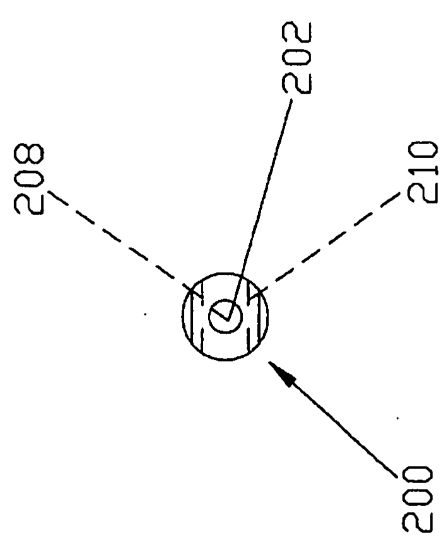


FIG. 7

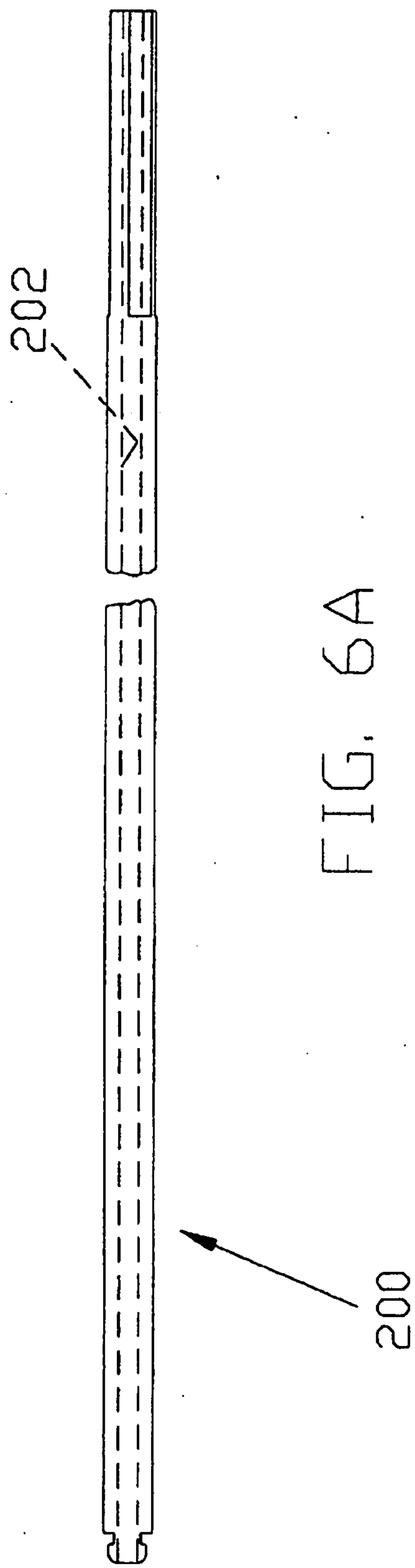


FIG. 6A

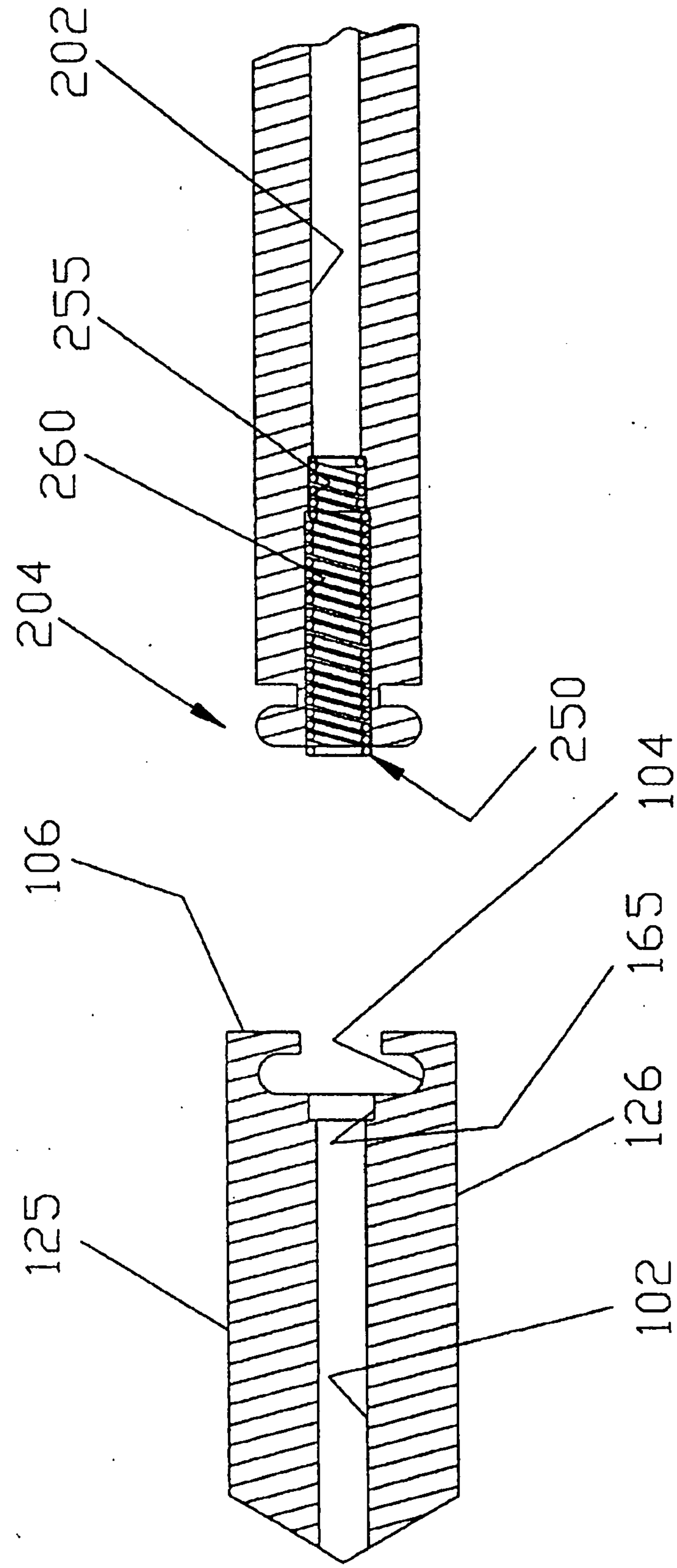


FIG. 7A

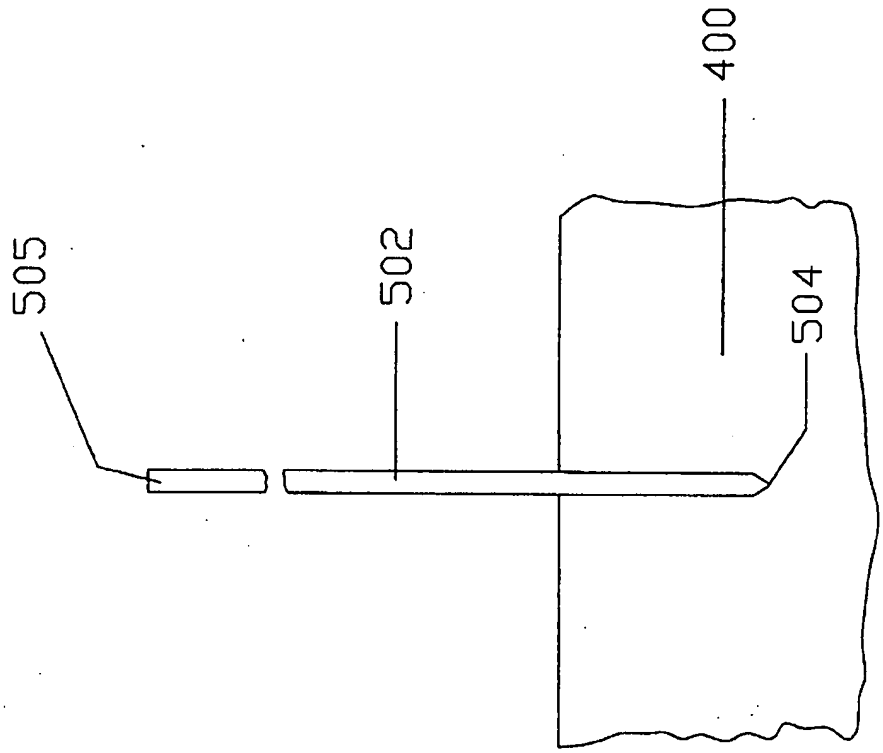


FIG. 10

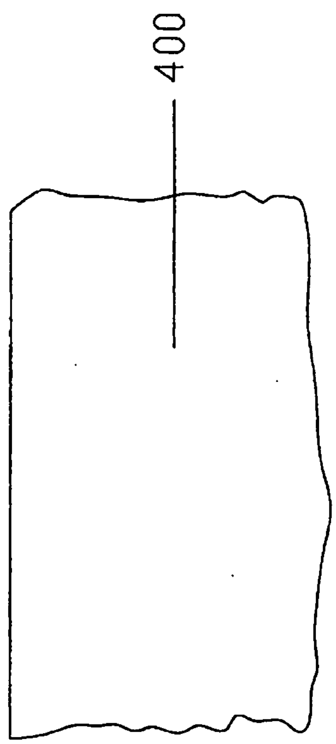


FIG. 9

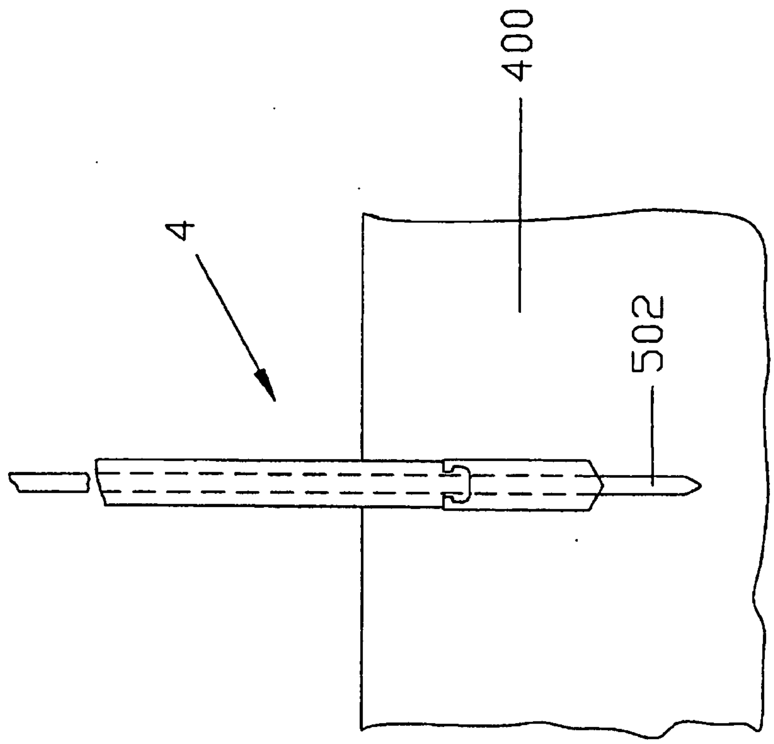


FIG. 12

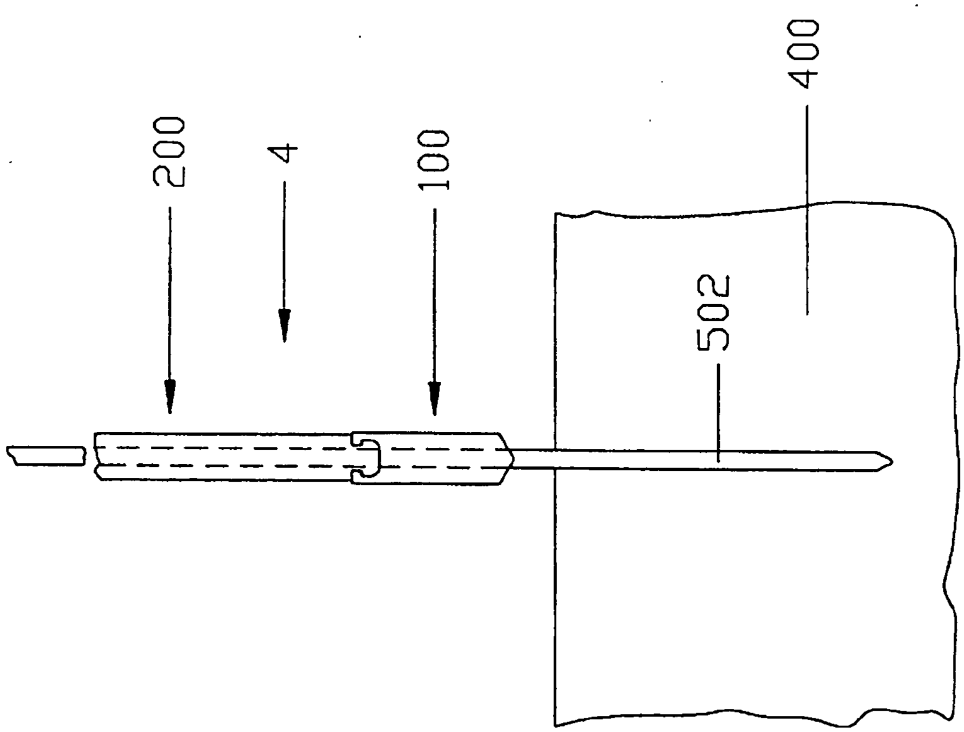


FIG. 11

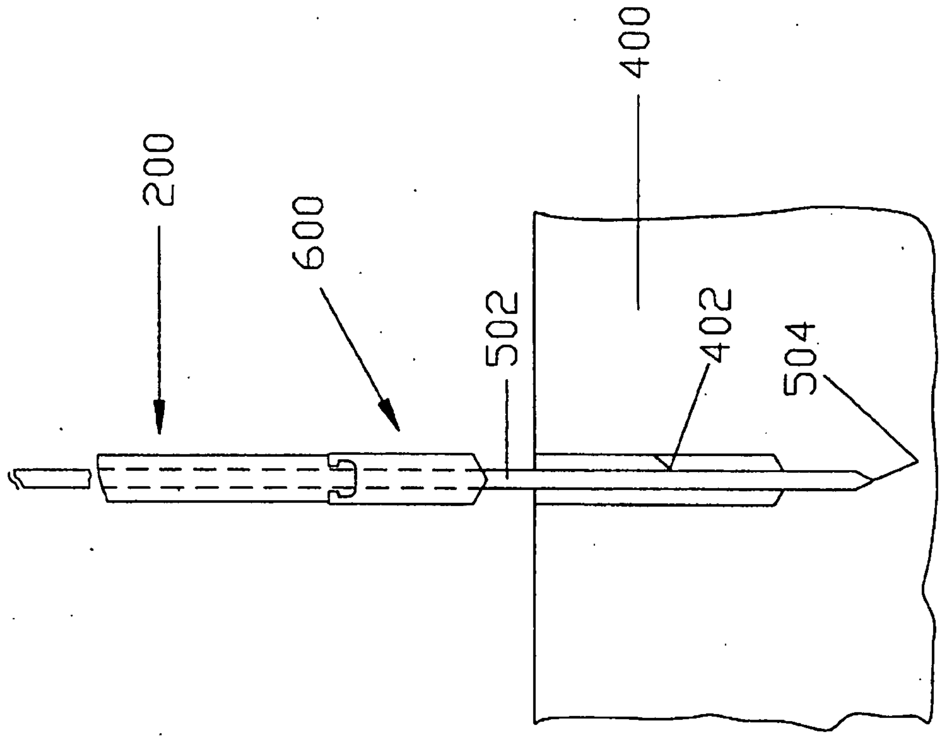


FIG. 14

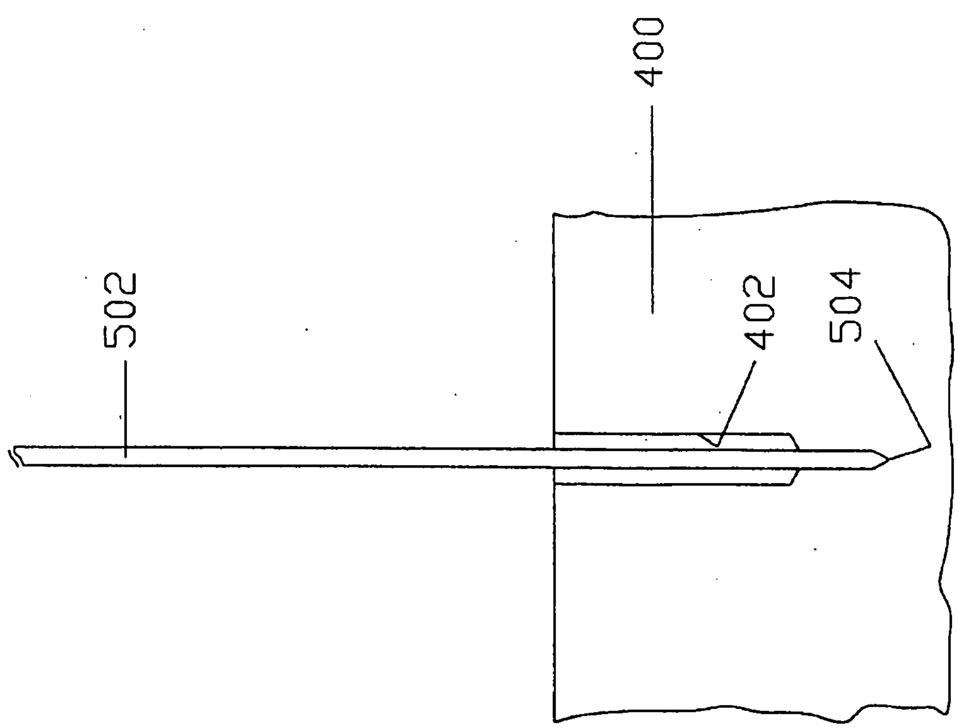


FIG. 13

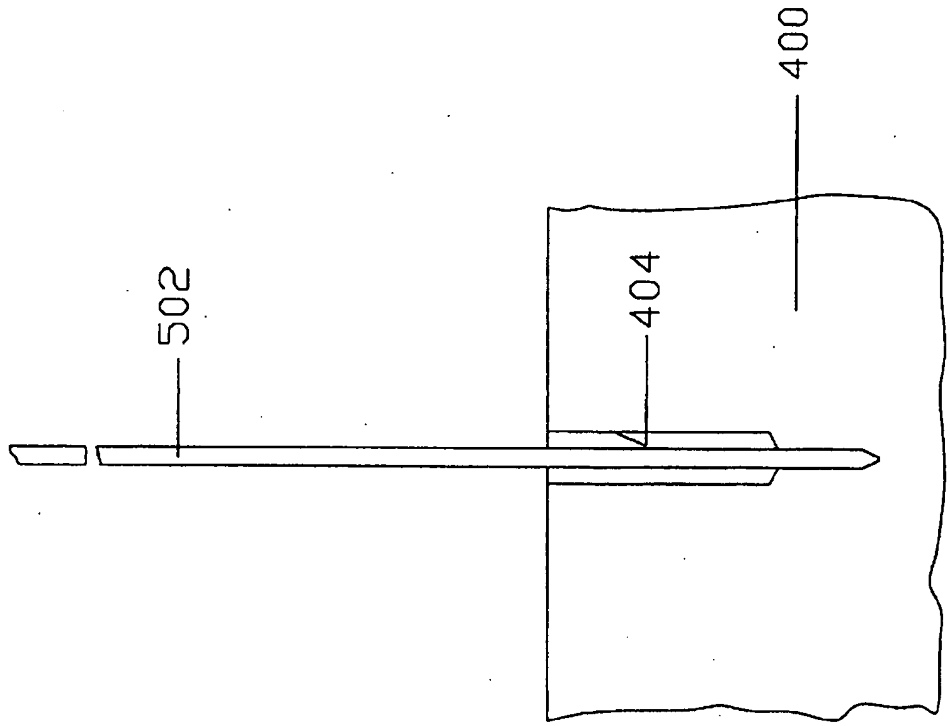


FIG. 16

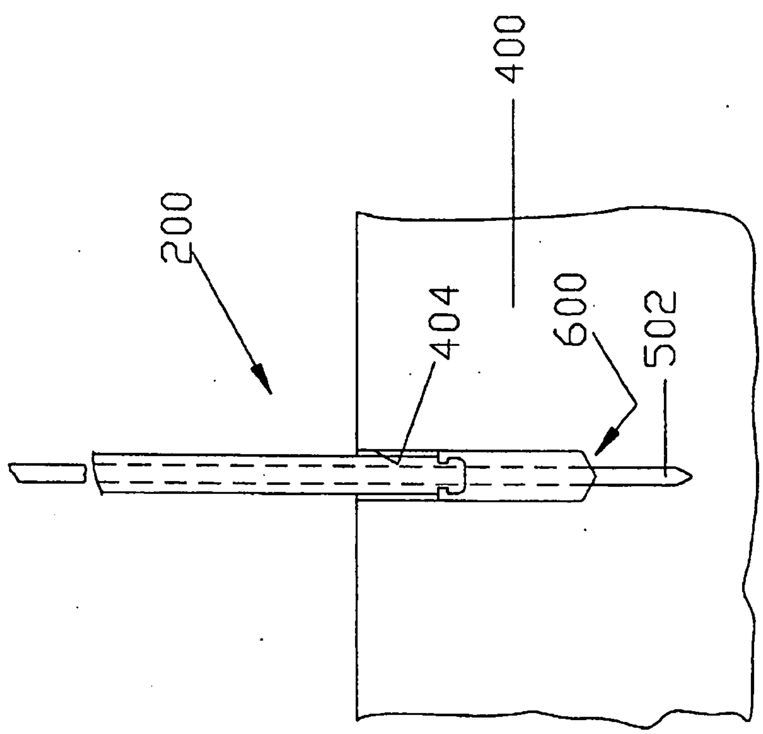


FIG. 15

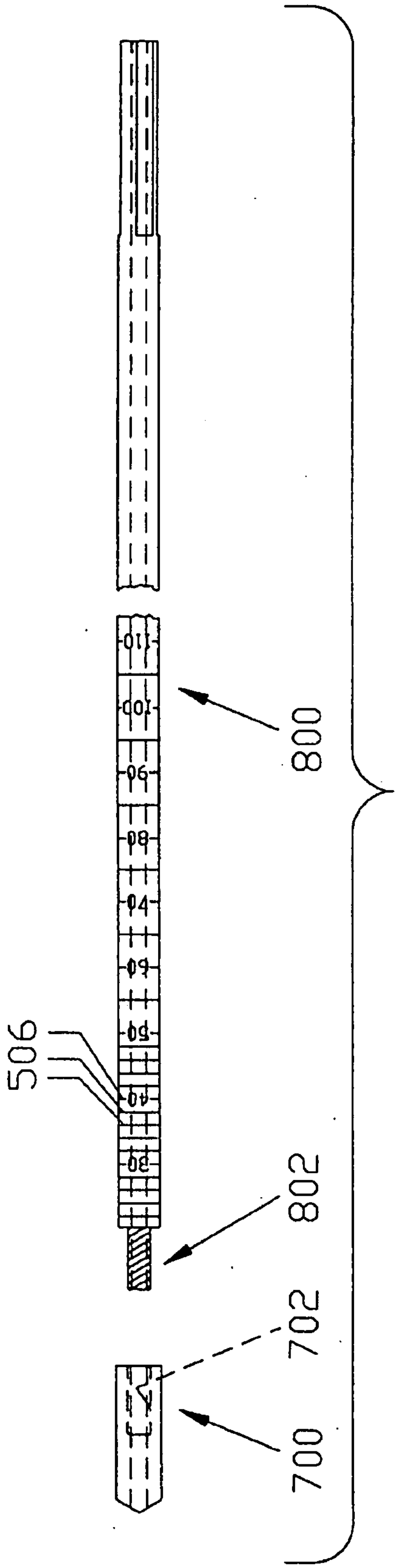


FIG. 20

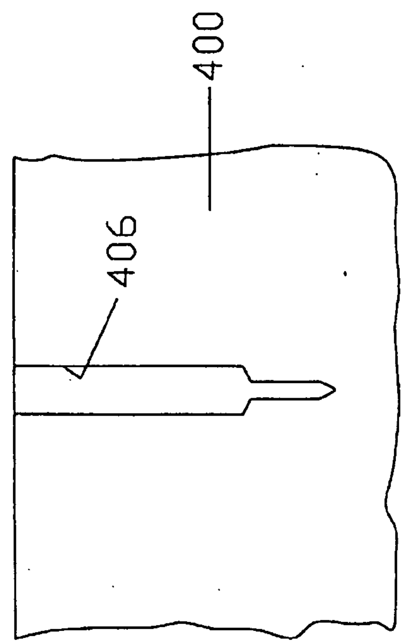


FIG. 17

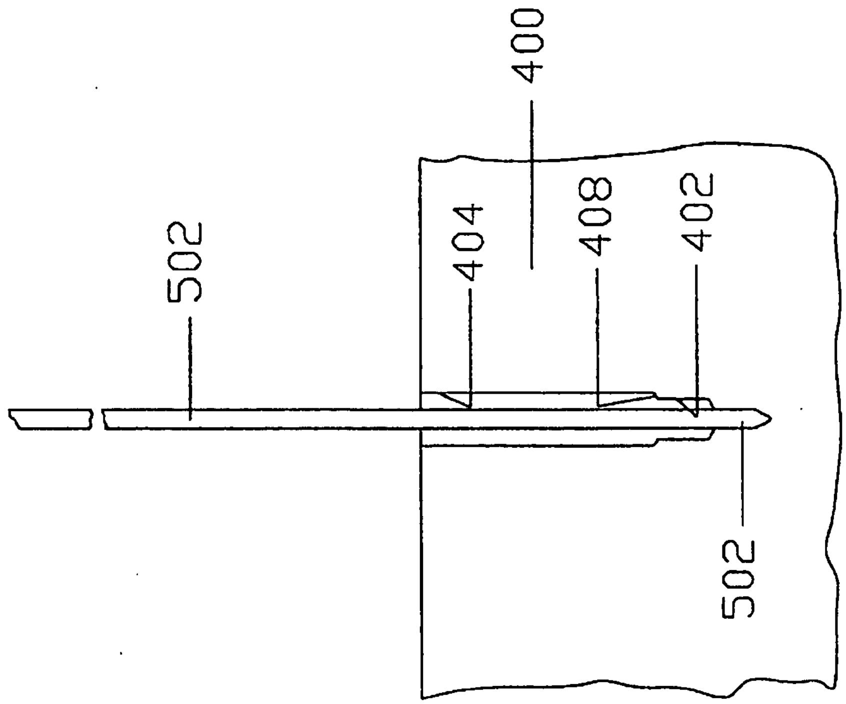


FIG. 19

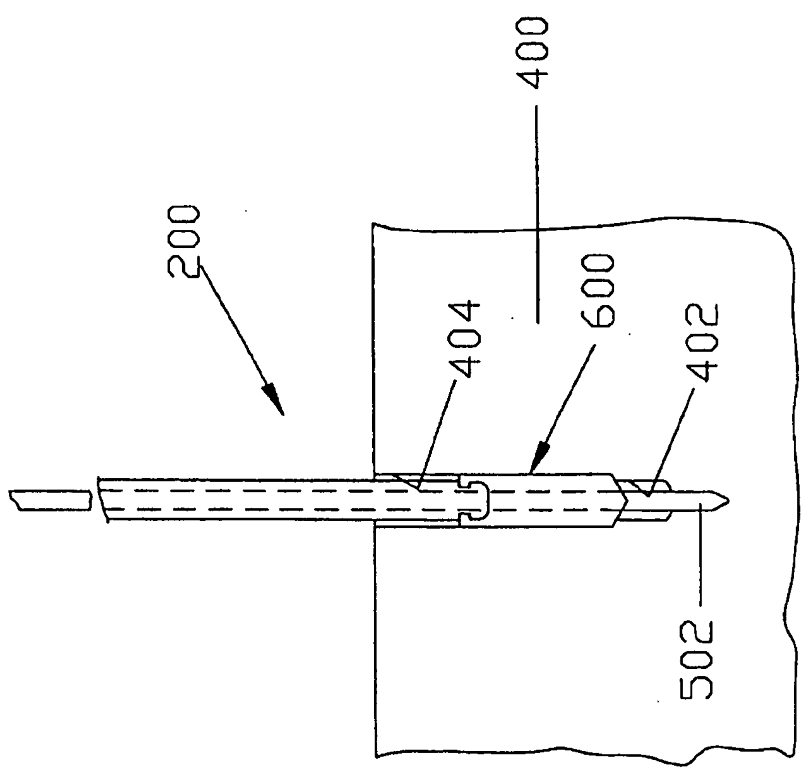


FIG. 18

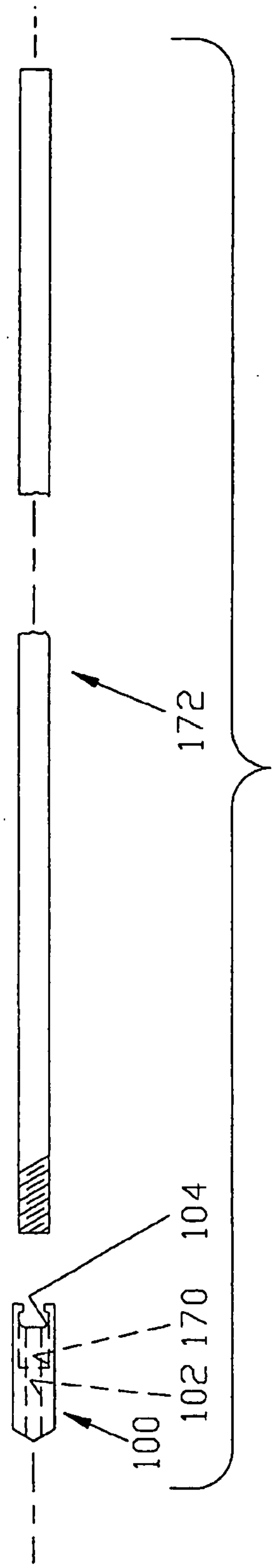


FIG. 20A

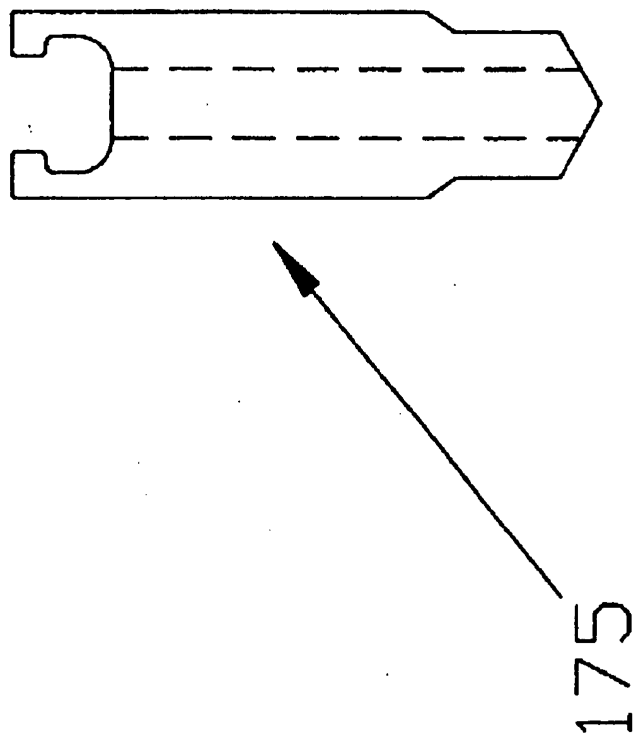


FIG. 20B

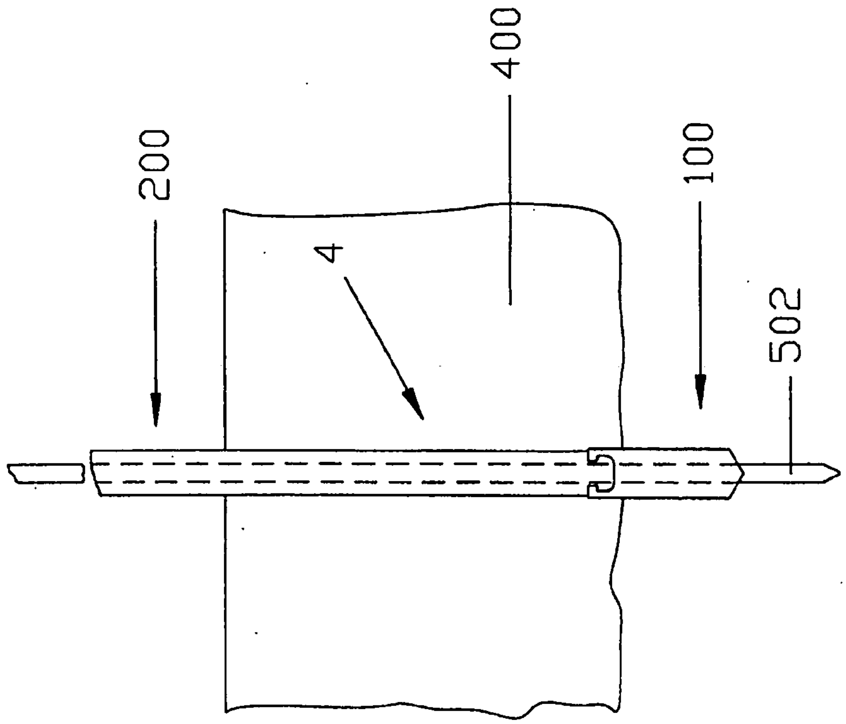


FIG. 22

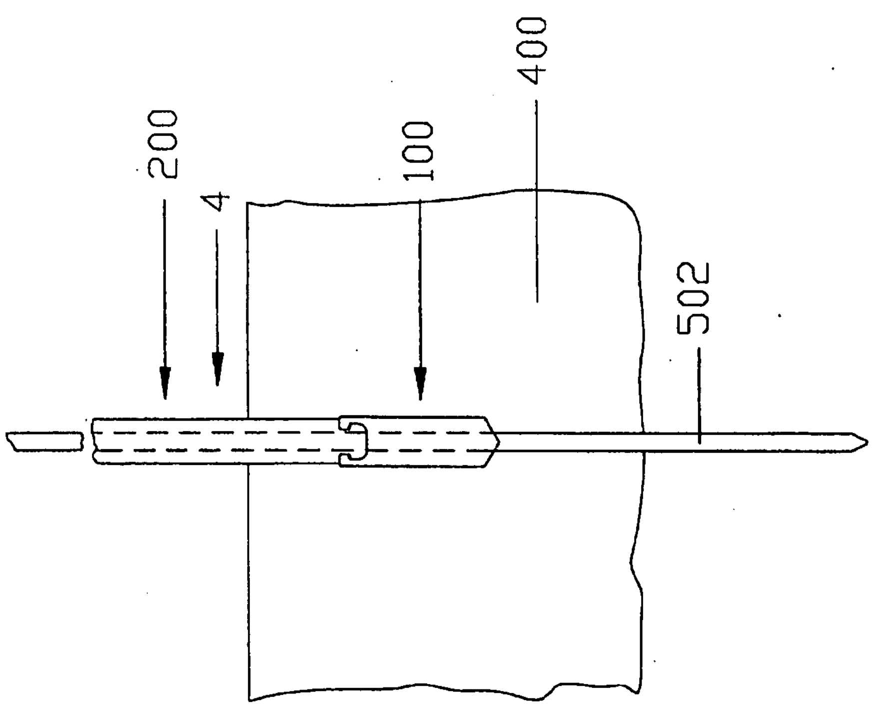


FIG. 21

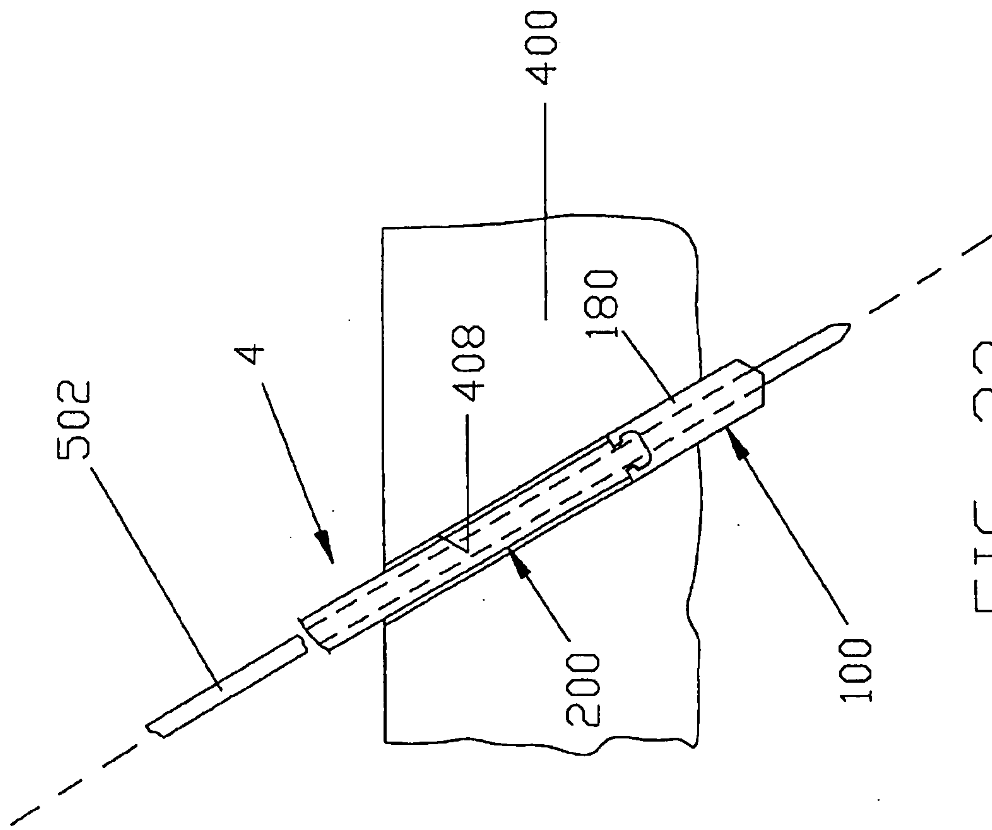


FIG. 23

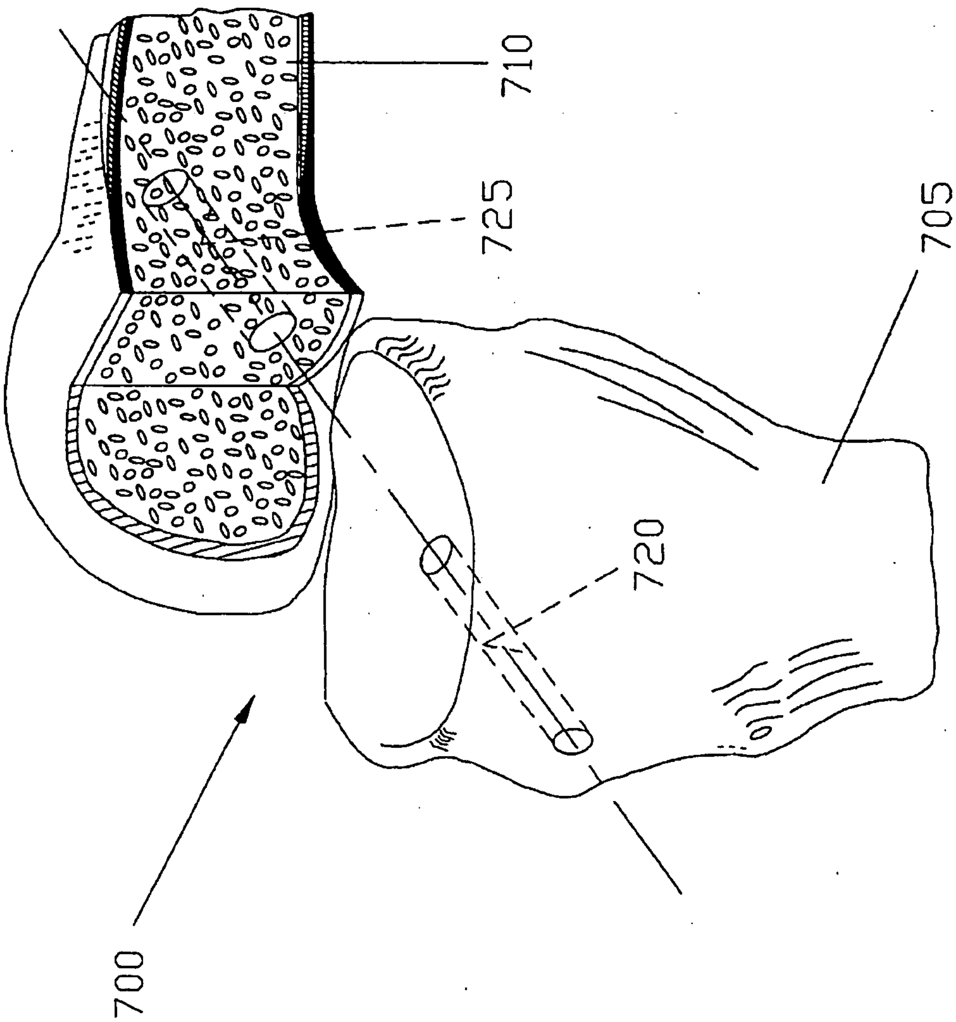


FIG. 24

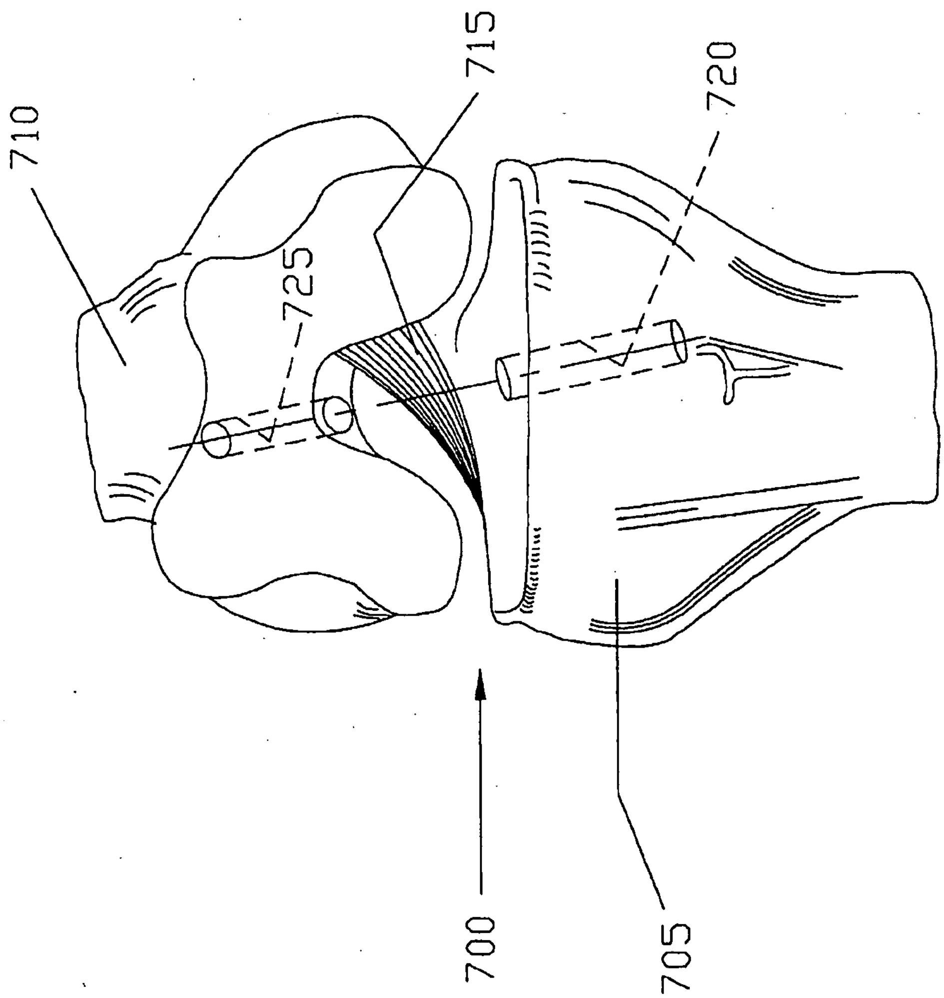


FIG. 25

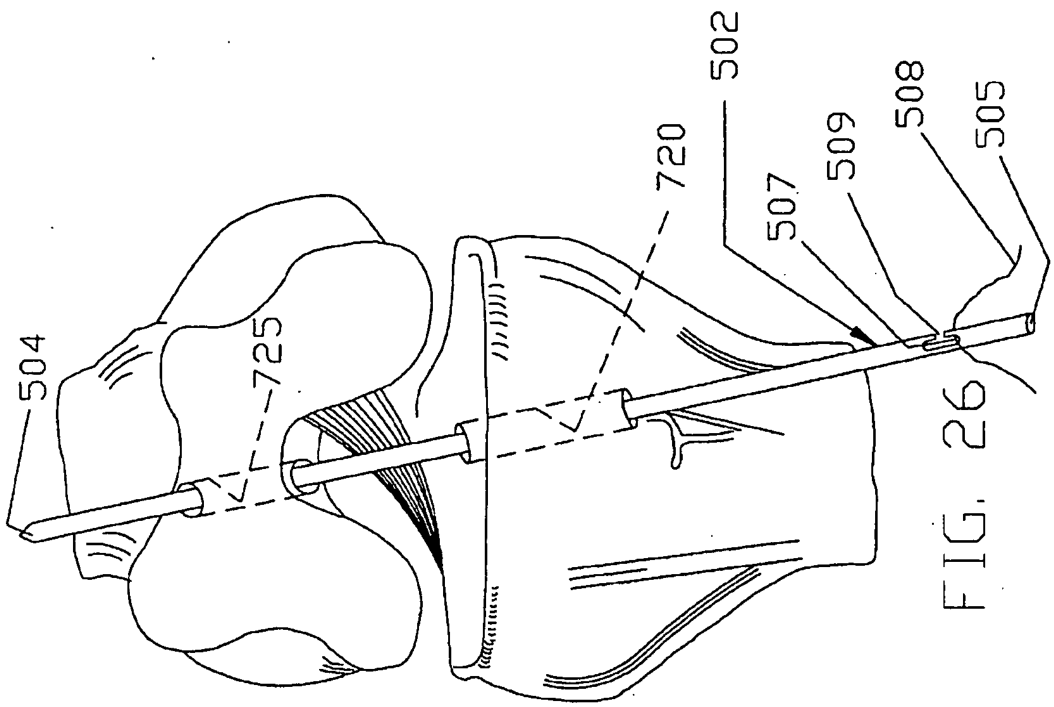


FIG. 26

MODULAR SURGICAL DRILL

FIELD OF THE INVENTION

The present invention relates to drilling implements for use in carrying out surgical procedures, and is more particularly concerned with a drill bit and shaft assembly which forms part of a surgical drilling implement.

BACKGROUND OF THE INVENTION

In carrying out certain surgical procedures, it is often necessary to form holes into or through bones. In some situations it may be necessary to form multiple holes having different diameters. It may also be necessary to form a hole in a bone on the first pass of a surgical drill of one diameter, and then to widen that hole (along either part of or all of its length) on a successive pass of a second, larger diameter drill.

To accomplish drilling into bone, one method that has been employed involves first placing a thin guidewire into a bone. Such a guidewire is frequently made of stainless steel. It is typically placed into the bone by tapping on the proximal end of the guidewire or by drilling. After the guidewire is thus installed, it is used to direct one or more drills down its length to effect a drilling operation. For example, the diameter of a tunnel that is formed into the bone using a first drill passed down a guidewire may be sequentially increased (along either part of or all of its length) by employing drills of increasingly larger size and passing them successively down the guidewire into drilling engagement with the bone.

Unfortunately, it can be time-consuming and inconvenient to successively chuck and remove multiple drill bits from a surgical drill during the course of a surgical procedure.

Accordingly, one object of the present invention is to provide a modular drill arrangement in which different drill bits may be readily interchanged on a rigid drill shaft in order to form different sized holes in bone.

Another object of the present invention is to provide a modular drill implement wherein a drill shaft need be chucked only once in a surgical drill in order to complete a surgical procedure which requires making different sized holes in bone.

A further object of the present invention is to provide a method of constructing tunnels in bone wherein a modular drill having a drill bit and a rigid drill shaft is employed in connection with a guidewire, and the interconnection of the drill bit and the rigid drill shaft is secured against displacement by the mounting of the modular drill on the guidewire.

Yet another object of the present invention is to provide a modular drill for use with a guidewire for drilling holes into bone wherein alignment of the drill bit is assured when drilling into bone even though the drill bit may be replaced with another drill bit during the surgical procedure.

A still further object of the present invention is to provide a surgical drilling implement which employs a drill bit and drill shaft, and wherein the interconnection between the drill bit and shaft is such as to readily permit interchanging drill bits, and wherein such drill bits are securely locked relative to the shaft.

Another object of the present invention is to provide a drill bit which, when drilled through bone and upon entering a joint capsule, will not damage adjacent soft tissue structures.

Yet another object of the present invention is to provide means for retrieving a drill bit which becomes disengaged from its associated drill shaft during use.

Still another object of the present invention is to provide improved means for mounting a drill bit to a drill shaft.

And another object of the present invention is to provide a modular drill which will avoid migrating off its drilling axis as it exits the far side of a bone even when that drilling axis extends at an acute angle to the rear surface of the bone.

Yet another object is to provide improved means for forming a bone tunnel through a bone, and thereafter passing a length of suture through that bone tunnel.

SUMMARY OF THE INVENTION

These and other objects of the present invention are achieved by providing a novel modular drill which employs a tongue and groove arrangement between one end of a drill bit and a mating end of a rigid drill shaft to effect attachment of one to the other. In addition, both the drill bit and the rigid drill shaft are formed with a through hole for mounting upon a guidewire after they are assembled to one another. A close fit is provided between the guidewire and the modular drill so as to prevent the drill bit and shaft from moving relative to one another once the preassembled drill has been mounted on the guidewire.

The method of employing such a modular drill contemplates that after the placement of a guidewire in a bone by means of drilling or tapping, a preassembled drill bit and shaft are placed onto the guidewire and passed down the guidewire into contact with the bone, whereupon the drill bit is advanced into the bone to a desired depth, or completely through the bone, to create a tunnel in the bone. Thereafter, the modular drill is removed from the guidewire. When desired, a modular drill bit of a different size may be mounted on the same drill shaft without removing the drill shaft from the chuck. If desired, drill bits of successively larger diameter may be mounted on the shaft and passed down the same guidewire so as to progressively enlarge the diameter of the tunnel thus created. The sizing of the through hole through the drill bit and the drill shaft relative to the diameter of the guidewire is such as to create a close sliding fit, thereby assuring that the drill bit and shaft cannot move relative to one another once the drill bit and drill shaft are mounted on the guidewire. Also, the fit between the guidewire and modular drill is such as to permit relative rotation therebetween.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention are more fully disclosed or rendered obvious by the following detailed description of the invention, which is to be considered together with the accompanying drawings wherein like numbers refer to like parts, and further wherein:

FIG. 1 is a side view illustrating a preferred form of the modular drill of the present invention and showing an assembled drill bit and rigid drill shaft;

FIG. 2 is an enlarged side view of the drill bit shown in FIG. 1;

FIG. 2A is a side view similar to FIG. 2, but showing the provision of a tightening element to help hold drill bit **100** on drill shaft **200**;

FIG. 3 is a front view of the drill bit of the present invention that is shown in FIG. 2;

FIG. 4 is a rear view of the drill bit of the present invention that is shown in FIG. 2;

FIG. 4A is a rear view similar to FIG. 4, but showing a somewhat rectangular rear end **106**;

FIG. 5 is a top view of the drill bit of the present invention that is shown in FIG. 2;

FIG. 6 is an enlarged side view of the rigid drill shaft shown in FIG. 1;

FIG. 6A is a side view similar to FIG. 6, but showing a dual diameter bore **202** extending the length of the shaft;

FIG. 7 is a front end view of the rigid drill shaft of the present invention that is shown in FIG. 6;

FIG. 7A is an exploded side view of another form of the modular drill of the present invention, showing the provision of a tightening element on the rigid drill shaft to help hold drill bit **100** on drill shaft **200**;

FIG. 8 is a rear end view of the rigid drill shaft of the present invention that is shown in FIG. 6;

FIG. 9 is a side view of a piece of bone to which the method of the present invention may be applied to create a tunnel in the bone;

FIG. 10 is a side view of a guidewire that has been inserted into the same piece of bone;

FIG. 11 is a side view of the same piece of bone, with an assembled modular drill being introduced onto the guidewire;

FIG. 12 is a side view of the same piece of bone, with the modular drill shown in FIG. 11 being advanced to cut into the bone to create a tunnel;

FIG. 13 is a side view of the same piece of bone after the modular drill shown in FIG. 12 has been withdrawn, with the guidewire still in place;

FIG. 14 is a side view of the same piece of bone showing the modular drill, having another drill bit of somewhat larger size, being introduced onto the guidewire;

FIG. 15 is a side view of the same piece of bone, with the second modular drill assembly shown in FIG. 14 being advanced to cut into the bone to enlarge the previously created tunnel in the bone;

FIG. 16 is a side view of the same piece of bone, after the second modular drill assembly shown in FIG. 15 has been withdrawn, with the guidewire still in place;

FIG. 17 is a side view of the same piece of bone after the guidewire has been removed;

FIG. 18 is a view like that of FIG. 15, except that the second modular drill assembly, having a drill bit of somewhat larger size than the first modular drill assembly, has stopped at a shallower depth than the first modular drill assembly previously passed down the same guidewire;

FIG. 19 is a side view of the same piece of bone after the second modular drill assembly shown in FIG. 18 has been withdrawn, with the guidewire still in place;

FIG. 20 is an exploded side view of another form of modular drill of the present invention, showing a different form of connection of the drill bit and drill shaft;

FIG. 20A is a an exploded side view showing a drill bit and retrieval means for retrieving the drill bit from the body in the event that it separates from the drill shaft during surgery;

FIG. 20B is a side view of a stepped profile drill bit also formed in accordance with the present invention;

FIG. 21 is a view like that of FIG. 12, except that the guidewire extends completely through bone **400**;

FIG. 22 is a view like that of FIG. 21, except that the modular drill is shown exiting the far side of bone **400**;

FIG. 23 is a side view of a piece of bone, showing a modular drill passing through the bone at an acute angle;

FIG. 24 is a side view of a knee joint, with bone tunnels extending in tibia **705** and femur **710**;

FIG. 25 is a front view of the same knee joint; and

FIG. 26 shows a guide wire with suture pulling means for passing a suture through a bone tunnel.

DETAILED DESCRIPTION OF THE INVENTION

A preferred embodiment of the modular drill bit and rigid drill shaft of the present invention is shown in FIGS. **1** through **8**, inclusive.

Looking first at FIG. **1**, there is shown a modular drill **4** which comprises two parts that are assembled together, i.e., a drill bit **100** and a rigid drill shaft **200**. In this preferred embodiment these two members are assembled together by means of a tongue-and-groove interconnection **300**. A bore **102** extends the full length of the drill bit **100**, and a bore **202** extends the full length of the shaft **200**. Bore **202** may have a constant diameter along its length, in which case the diameter of bore **202** is substantially the same as the diameter of bore **102** (see FIGS. 1 and 6). Alternatively, bore **202** may have two or more different diameters along its length, in which case the smallest of these diameters is substantially the same as the diameter of bore **102** and the remaining diameters are somewhat larger in size (see FIG. 6A). This latter arrangement is preferred in some cases so as to minimize any binding of the rigid shaft **200** on the guidewire during drilling. Regardless of whether bore **202** is formed with a single diameter or multiple diameters, the two bores **102** and **202** are in alignment when the drill bit **100** is interconnected to the drill shaft **200** as shown in FIG. **1**.

The details of the drill bit construction are more clearly shown in FIGS. **2**, **3**, **4** and **5**. One portion of the tongue-and-groove interconnection **300** is provided in the drill bit **100** by forming a "D" shaped groove **104** (see FIG. **2**) at the rear end **106** of the drill bit. The rear end **106** may be formed circular in shape for relatively small drill bits (see FIGS. **2–5**), or it may be formed somewhat rectangular in shape (with fully radiused surfaces **125** and **126**, as will hereinafter be discussed in further detail) for relatively large drill bits (see FIG. 4A). In either case, groove **104** passes completely through rear end **106**, extending from one side **110** to the other side **112** (see FIG. **5**) of the drill bit **100**. This construction results in creating opposed depending locking ribs **116** and **120** (FIG. **2**).

Drill bit **100** has a spade type configuration. As seen in FIG. **5**, the sides **110** and **112** are sloped towards one another in the direction extending from the rear end **106** of the drill bit towards the forward end **124** (FIGS. **2** and **5**). The specific angle of these sides to the center line of the drill bit is not critical. The angles are chosen such as to enable the drill to be turned smoothly into bone and to allow bone chips to flow away from the drill tip. At the same time, the drill bit's two other surfaces **125** and **126** are curved surfaces which lie along a constant radius projected from the longitudinal axis of the drill bit. In other words, curved surfaces **125** and **126** are full radiused projections from the longitudinal axis of the drill bit (see FIGS. **3**, **4** and 4A). Surfaces **110**, **112**, **125** and **126** meet at corner edges **127A**, **127B**, **127C** and **127D** (see FIGS. **3** and 4A).

The configuration of the front end **124** of the drill bit is shown more clearly in FIGS. **2** and **3**, when considered along with FIG. **5**. The front end **124** is formed by two surfaces **128** and **130** which slope towards one another and meet at their apex. The bore **102** extends through the front end **124** to open on surfaces **128** and **130**, thereby creating a concave rim **131** (see FIG. **5**) bounded by apex edges **132** and **133** (see FIG. **3**). Surfaces **128** and **130** are each formed with a relief angle, so that surface **128** slopes off from left to right, and surface **130** slopes off from right to left, when viewed from the point of reference of FIG. **3**. Side edges **134** and **135** form the cutting edges for cutting into bone when the drill bit is rotated counterclockwise, when viewed from the point of reference of FIG. **3**.

The other part of the tongue-and-groove interconnection **300** is formed at the front end of the rigid shaft **200** (see FIGS. **6** and **7**). The front end of the drill shaft is in the form of a "D" shaped tongue **204** (see FIG. **6**) of lesser diameter **206** than the diameter of the shaft **200**. Tongue **204** is complementary in shape to the "D" shaped groove **104** in the drill bit **100**. Tongue **204** is slightly forward of the main body of shaft **200** in order to form the locking slots **208** and **210**. This construction enables the drill bit **100** to be locked to the rigid drill shaft **200** when the groove **104** is passed over the tongue **204** and the locking ribs **116** and **120** are placed into the locking slots **208** and **210**, respectively.

If desired, and looking now at FIG. **2A**, a tightening element **160** (such as a curved or conical spring washer) may be provided to help hold drill bit **100** on shaft **200**. In such a case, drill bit **100** includes a counterbore **165** that is coaxial with bore **102**. Tightening element **160** is seated in, and normally projects out of, counterbore **165** so as to be capable of yieldably projecting into groove **104**. As a result of this construction, when groove **104** passes over tongue **204**, tightening element **160** engages tongue **204** and thereby helps retain drill bit **100** on shaft **200**.

Alternatively, and looking now at FIG. **7A**, a tightening element **250** (such as an ordinary compression spring) may be provided on rigid drill shaft **200** to help hold drill bit **100** on the drill shaft. In this case, rigid drill shaft **200** includes a first counterbore **255** and a second counterbore **260**. First counterbore **255** has a smaller diameter than second counterbore **260**, and first counterbore **255**, second counterbore **260** and tightening element **250** are sized so that the tightening element will make a binding fit with the walls of first bore **255**, yet will yieldably project out of second counterbore **260**. At the same time, tightening element **250** is hollow, with its internal diameter being greater than the diameter of the guidewire so that the guidewire can be accommodated therein. As a result of this construction, when groove **104** passes over tongue **204**, tightening element **250** will engage drill bit **100** and then seat in the drill bit's counterbore **165** so as to help hold drill bit **100** on shaft **200**.

The main body of shaft **200** is generally cylindrical in form, however, at its rear end **212** it is formed with a configuration which enables the shaft to be mounted into a chuck of a surgical drill. As shown in FIGS. **6** and **8**, three flattened surfaces **214**, **216** and **218** are formed at the rear end **212** and extend forward for a short distance from the shaft's rear end surface **219**. For example, the surface **214** extends forward to and terminates at the shoulder **220** (see FIG. **6**).

To employ the modular drill in a surgical procedure, the rear end **212** of shaft **200** is first tightened in a drill chuck (not shown). Then the drill bit **100** is assembled to the drill shaft **200** by positioning the drill bit's groove **104** adjacent to the shaft's tongue **204** and then sliding the bit sideways so that the locking ribs **116** and **120** are positioned within the locking slots **208** and **210**, as indicated above, and the bores **102** and **202** are aligned.

Next, the thus assembled modular drill **4** may be employed to form a tunnel of desired diameter in bone, such as the piece of bone **400** shown in FIG. **9**. The method involves the use of a guidewire **502** having a pointed end **504** and a free end **505**. As indicated previously, this guidewire is preferably made of a surgically compatible material, e.g. stainless steel. The guidewire is first tapped or drilled into the bone **400** to a desired depth as shown in FIG. **10**. Thereafter, a preassembled modular drill **4**, chucked into a surgical drill (not shown), is moved down the guidewire (see FIG. **11**) until it is in contact with the bone **400**. The drill is then advanced along the guidewire into the bone (as shown in FIG. **12**) so as to create a hole to a desired depth. After reaching such desired depth the modular drill is removed, thus leaving a hole **402** (FIG. **13**) having the shape and dimensions of the drill bit that was employed to form the hole.

Where it is desired to provide an enlarged hole or tunnel in the bone, the guidewire **502** is allowed to remain in the bone **400**, protruding therefrom as seen in FIG. **13**. A larger sized drill bit **600** is then mounted on the same drill shaft **200**. This can be done without removing shaft **200** from the surgical drill's chuck. The newly assembled modular drill is then passed down the guidewire **502** until it is in contact with the bone mass **400**. The modular drill is then advanced down the guidewire (FIG. **15**) in order to form the larger diameter bore or tunnel **404**. The drilling implement is then removed from the bone and the larger diameter tunnel **404**, with the guidewire **502** still protruding from the bone as seen in FIG. **16**. Where still larger diameter holes are desired, this process can be repeated with still larger sized drill bits. Finally, when the desired diameter tunnel **406** has been created in the bone **400**, the guidewire is removed (see FIG. **17**).

The same procedure may be used to drill a stepped bone tunnel, where the larger diameter hole **404** is drilled to a shallower depth than the initial diameter hole **402**, thereby leaving an annular shoulder **408** at the base of the larger diameter hole **404** (see FIGS. **18** and **19**).

The entire drilling procedure employs a guidewire **502** which has a diameter of such dimension as to create a close sliding fit in the aligned bores **102** and **202** of the modular drill. Such an arrangement keeps the drill bit and shaft from moving relative to one another because of the mounting on the guidewire, while still enabling rotation of the modular drill on the guidewire to effect drilling into the bone. Further, the retention of the guidewire in the bone **400** during all drilling ensures that the hole or tunnel that is produced is on the same center line regardless of the number of drilling steps that are performed. This alignment is maintained even though successive drilling operations are applied to the bone, using different drill bits, since the modular drill assembly always moves down the same, fixed guidewire.

In order to facilitate drilling to a desired depth, rigid drill shaft **200** may have graduated markings **506** (see FIGS. **6** and **20**) along its length to indicate the position of the drill bit tip relative to the outer surface of the bone.

The foregoing constitute only some of the possible forms of the present invention, which comprises a novel modular drill and a method of its use in forming tunnels into bone wherein the drill shaft need be mounted only once in the

chuck of a drill, and the drill bits may be easily interchanged during the surgical procedure without having to dismount the shaft from the drill. It is also to be appreciated, of course, that various changes may be made in the configuration of the drill bit and/or the drill shaft, the materials of which they are made and the manner in which they are used, all without departing from the spirit and scope of the present invention.

Thus, for example, while in the preferred embodiment of FIGS. **1–8**, a tongue-and-groove interconnection is employed between the drill bit and drill shaft, a threaded connection may also be used. Such an arrangement is shown in FIG. **20**, wherein a drill bit **700** having a threaded bore **702** is provided, along with a drill shaft **800** having a reduced threaded forward end **802**. In this modification, the drill bit **700** is threaded onto the drill shaft **800**. Standard threads or special thread forms may be used.

Alternatively, other known attachment means may be used to attach the drill bit to the drill shaft. By way of example, a dovetail mount or a bayonet mount may also be used.

In a further embodiment of the invention, the drill bit may be provided with retrieval means for retrieving the drill bit from the body in the event that it separates from the drill shaft during surgery. Thus, for example, and looking now at FIG. **20**A, a threaded portion **170** is tapped into bore **102** to a specific depth. In the event that the drill bit becomes disengaged from the drill shaft during surgery, it can be retrieved by means of a threaded retrieval tool **172**, also shown in FIG. **20**A. During retrieval, the tool **172** is screwed into threaded portion **170**, thereby allowing tool **172** to capture the drill bit for subsequent removal.

Also, although a drill bit having only one cutting profile has been shown and described above, it is also possible to form the drill bit with a plurality of cutting profiles, including a profile which includes more than one diameter. Thus, for example, and looking now at FIG. **20**B, a two diameter spade type bit **175** is shown. Drill bit **175** may be employed to provide a stepped hole with a single pass of the modular drill. Alternatively, an exiting hole may be widened along some or all of its length by placing the stepped profile drill bit **175** into the exiting hole and drilling.

Although the modular drill has been generally described in the context of FIGS. **9–19** as being used to establish and progressively widen a bone tunnel, it could be used to drill a plurality of different holes in bone of varying size during a given surgical procedure. In either case there is the advantage of not having to re-chuck the drill in the surgical drilling implement each time a different size hole or larger diameter hole is to be drilled. It is only necessary to interchange the drill bit on the drill shaft.

Additionally, although what has been described is the creation of one or more tunnels in bone that are "dead-ended", the modular drill could be used to drill all the way through the bone. See, for example, FIGS. **21** and **22**, which are similar to the foregoing FIGS. **11** and **12**, except that they show the guidewire **502** and drill **4** passing completely through bone **4**.

Furthermore, FIGS. **9–19**, **21** and **22** show the use of the modular drill to create a tunnel in bone that is perpendicular to the outer surface of the bone. However, a hole may also be drilled at an angle to the vertical. FIG. **23** depicts drilling a through hole in a bone **400**, at an angle to the vertical. The modular drill **4** is used to create the tunnel **408** in the manner described above. However, even though the guidewire **502** is deployed to align the drill, when the drill bit **100** drills through the other side of the bone, the guidewire becomes dislodged. It is possible, when this occurs, for the drill bit to migrate off-axis and/or to cause the exit portion of the tunnel to be widened, or become non-circular, or otherwise be deformed so that the tunnel is not of constant diameter throughout its length. This could seriously impair the surgical procedure. To avoid such a result it is important that the length of the drill bit be greater than its diameter, and that the drill bit be of relatively constant diameter. In practice, it has been found that where the length of the drill bit is at least twice its maximum diameter, a stable exit from the bone hole will be attained for a variety of angles. This result is illustrated in FIG. **23**, which shows the drill bit **100** advanced through the bone, with the rear portion **180** of the drill bit still serving to guide and steady the modular drill to ensure that a linear tunnel **408** is created.

These and other changes of their type are all considered to be within the spirit and scope of the present invention.

It is anticipated that the present invention will have particular application in surgical procedures for ligament reconstruction. More particularly, in U.S. Pat. Nos. 4,772,286 issued Sep. 20, 1988 to Goble et al.; 4,927,421 issued May 22, 1990 to Goble et al.; 4,997,433 issued Mar. 5, 1991 to Goble et al.; 5,147,362 issued Sept. 15, 1992 to Goble; and Re. 34,293 issued Jun. 22, 1993 to Goble et al., a variety of devices and methods are disclosed for attaching a ligament (or a ligament substitute) to bone, in order that a detached ligament may be reattached to bone or a damaged ligament completely replaced. In all of the methods disclosed in the foregoing patents, it is necessary to form a hole completely through the tibia and a hole at least part way (or all the way) through the femur, with the tibial and femoral holes being aligned with one another. Thus, for example, in FIGS. **24** and **25**, a knee joint **700** is shown where a tibia **705** and a femur **710** come together. A posterior cruciate ligament (PCL) **715** is shown extending between tibia **705** and femur **710**. In order to replace or reconstruct the anterior cruciate ligament (ACL) using one of the methods disclosed in one of the aforementioned patents, it is necessary to bend the knee joint into the desired position and then drill a hole **720** through tibia **705** and a hole **725** into femur **710**. Depending on which one of the methods is to be used, hole **725** may extend only part way through femur **710** or all the way through femur **710**. Regardless, it is necessary that the holes **720** and **725** be aligned with one another.

The present invention provides an excellent means of forming bone holes **720** and **725**. More particularly, once the knee has been put into the desired position, a guidewire is passed through tibia **705** and into femur **710**. Depending on the circumstances, the guidewire may or may not exit on the far side of femur **710**. Then a drill formed in accordance with the present invention is passed all the way through tibia **705** and part way or all the way through femur **710**. Thereafter, one or both of the holes **720** and **725** may be enlarged, either part way or all the way along their length, simply by placing a larger drill bit on the drill shaft and passing the drill back down the guidewire, in the manner previously disclosed. Of course, bone hole **720** and **725** may also be formed in separate and distinct drilling steps, with equally beneficial results.

It will be appreciated that in an anterior cruciate ligament (ACL) reconstruction procedure such as that shown in FIGS. **24** and **25**, it is important that the existing body structure not be inadvertently damaged during the hole-forming process. In particular, in the example of FIGS. **24** and **25**, it is important that the posterior cruciate ligament (PCL) not be damaged by the drill as the holes **720** and **725** are formed. To this end, the drill bit's fully radiused surfaces **125** and

126 will avoid snagging or ripping or tearing the PCL if the drill bit should inadvertently contact the PCL during drilling.

Finally, in many surgical procedures the surgeon will need to pass a suture through a bone tunnel after the bone tunnel is formed. To this end, and looking now at FIG. 26, guidewire 502 may be provided with a side slotted eyelet 507 adjacent to its free end 505. A suture 508 is looped through the side slot 509 of eyelet 507 so that it will be captured by the eyelet. The suture may thereafter be drawn through one or more bone tunnels (e.g. the bone tunnels 720 and 725 shown in FIG. 26) by pulling the guidewire, pointed end 504 leading, through the one or more bone tunnels.

It is also to be appreciated that the modular drill of the present invention can be used to form holes in workpieces other than bone, in circumstances which may or may not relate to human and/or animal surgery. For example, the modular drill can be used to form a hole in a workpiece made of wood and/or plastic and/or metal, where the workpiece is entirely unrelated to human and/or animal surgery.

Still other uses for the novel apparatus and method of the present invention will be obvious to those skilled in the art.

What is claimed is:

1. A modular drill which is employed with a surgical drill tool for forming holes in bone, said modular drill comprising:

a drill bit having at least one cutting edge on one end thereof, and having a longitudinally extending bore passing through said drill bit;

a rigid drill shaft having mounting means at one end thereof for mounting said drill shaft on the surgical drill tool, and having a longitudinally extending bore passing through said drill shaft; and

releasable interconnecting means formed on other ends of said drill shaft and said drill bit permitting assembly and disassembly of said drill bit to and from said drill shaft, said releasable interconnecting means being formed such that said bore passing through said drill bit is aligned with said bore passing through said drill shaft when said drill bit is assembled to said drill shaft, said releasable interconnecting means comprising a tongue-and-groove interconnection; said drill shaft comprising a central body portion, and a D-shaped tongue portion formed at said other end of said drill shaft and spaced slightly forward of said central body portion, wherein a pair of locking slots are formed in the space between said tongue portion and said central body portion of said drill shaft.

2. The modular drill of claim 1 wherein said other end of said drill bit is formed with a D-shaped groove.

3. The modular drill of claim 2 wherein said other end of said drill bit is provided with a pair of locking ribs extending into and adjacent to said D-shaped groove.

4. The modular drill of claim 1 wherein said drill bit further comprises a threaded counterbore adapted to be engaged by a threaded retrieval tool, whereby said drill bit may be captured by said retrieval tool when said drill bit is separated from said drill shaft.

5. A modular drill which is employed with a surgical drill tool for forming holes in bone, said modular drill comprising:

a drill bit having at least one cutting edge on one end thereof, and having a longitudinally extending bore passing through said drill bit;

a rigid drill shaft having mounting means at one end thereof for mounting said drill shaft on the surgical drill tool, and having a longitudinally extending bore passing through said drill shaft; and

releasable interconnecting means formed on other ends of said drill bit and said drill shaft permitting assembly and disassembly of said drill bit to and from said drill shaft, said releasable interconnecting means being formed such that said bore passing through said drill bit is aligned with said bore passing through said drill shaft when said drill bit is assembled to said drill shaft;

wherein said releasable interconnecting means comprises a tongue-and-groove interconnecting means, a portion of which is located on said other ends of said drill bit and said drill shaft; and

wherein a tongue portion is located on said other end of said rigid drill shaft, and a groove portion is located on said other end of said drill bit, and further wherein said groove portion comprises a counterbore, and spring means protruding therefrom, said spring means being adapted to engage said tongue portion when said drill bit and said drill shaft are assembled together.

6. A modular drill which is employed with a surgical drill tool for forming holes in bone, said modular drill comprising:

a drill bit having at least one cutting edge on one end thereof, and having a longitudinally extending bore passing through said drill bit;

a rigid drill shaft having mounting means at one end thereof for mounting said drill shaft on the surgical drill tool, and having a longitudinally extending bore passing through said drill shaft; and

releasable interconnecting means formed on other ends of said drill bit and said drill shaft permitting assembly and disassembly of said drill bit to and from said drill shaft, said releasable interconnecting means being formed such that said bore passing through said drill bit is aligned with said bore passing through said drill shaft when said drill bit is assembled to said drill shaft;

wherein said releasable interconnecting means comprises a tongue-and-groove interconnecting means, a portion of which is located on said other ends of said drill bit and said drill shaft; and

wherein a tongue portion is located on said other end of said rigid drill shaft, and a groove portion is located on the other end of said drill bit, and further wherein said tongue portion comprises a counterbore, and spring means protruding therefrom, said spring means being adapted to engage said groove portion when said drill bit and said drill shaft are assembled together.

7. The modular drill of claim 6 wherein said groove portion comprises a counterbore, said spring means being adapted to seat in said groove portion counterbore when said drill bit and said drill shaft are assembled together.

8. A modular drill which is employed with a surgical drill tool for forming holes in bone, said modular drill comprising:

a drill bit having at least one cutting edge on one end thereof, and having a longitudinally extending bore passing through said drill bit;

a rigid drill shaft having mounting means at one end thereof for mounting said drill shaft on the surgical drill tool, and having a longitudinally extending bore passing through said drill shaft; and

releasable interconnecting means formed on other ends of said drill bit and said drill shaft permitting assembly and disassembly of said drill bit to and from said drill shaft, said releasable interconnecting means being formed such that said bore passing through said drill bit

is aligned with said bore passing through said drill shaft when said drill bit is assembled to said drill shaft;

wherein said releasable interconnecting means comprises a tongue-and-groove interconnecting means, a portion of which is located on said other ends of said drill bit and said drill shaft; and

wherein said drill bit further comprises a counterbore and spring means protruding therefrom, said spring means being adapted to engage said drill shaft when said drill bit and said drill shaft are assembled together.

9. A modular drill which is employed with a surgical drill tool for forming holes in bone, said modular drill comprising:

a drill bit having at least one cutting edge on one end thereof, and having a longitudinally extending bore passing through said drill bit;

a rigid drill shaft having mounting means at one end thereof for mounting said drill shaft on the surgical drill tool, and having a longitudinally extending bore passing through said drill shaft; and

releasable interconnecting means formed on other ends of said drill bit and said drill shaft permitting assembly and disassembly of said drill bit to and from said drill shaft, said releasable interconnecting means being formed such that said bore passing through said drill bit is aligned with said bore passing through said drill shaft when said drill bit is assembled to said drill shaft;

wherein said releasable interconnecting means comprises a tongue-and-groove interconnecting means, a portion of which is located on said other ends of said drill bit and said drill shaft; and

wherein said drill shaft further comprises a counterbore and spring means protruding therefrom, said spring means being adapted to engage said drill bit when said drill bit and said drill shaft are assembled together.

10. A modular drill assembly comprising:

a guidewire comprising a first end and a second end, said first end being pointed to facilitate releasably embedding said first end of said guidewire in bone; and

a modular drill comprising:

a drill bit having at least one cutting edge on one end thereof, and having a bore extending from one end to the other end of said drill bit;

a drill shaft having mounting means at one end thereof for mounting said drill shaft to a surgical drill tool and having a bore extending from one end to the other end of said drill shaft;

the respective bores sized with respect to the diameter of said guidewire so as to provide a close sliding fit therewith; and

releasable interconnecting means formed in part on the other ends of said drill bit and said rigid drill shaft permitting assembly and disassembly of said drill bit to and from said drill shaft, said releasable interconnecting means comprising a tongue-and-groove interconnection and being formed such that said bore passing through said drill bit is aligned with said bore passing through said drill shaft when said drill bit is assembled to said drill shaft;

said drill shaft comprising a central body portion and a tongue portion formed at said other end of said drill shaft and spaced slightly forward of said central body portion, wherein a pair of locking slots are formed in the space between said tongue portion and said central body portion of said drill shaft; and

whereby when said modular drill is mounted on said guidewire, said drill bit and said rigid drill shaft may not move relative to one another.

11. A modular drill which is employed with a surgical drill tool for forming holes in bone, said modular drill comprising:

a drill bit having at least one cutting edge on one end thereof, and having a longitudinally extending bore passing through said drill bit;

a rigid drill shaft having mounting means at one end thereof for mounting said drill shaft on the surgical drill tool, and having a longitudinally extending bore passing through said drill shaft; and

releasable interconnecting means formed on other ends of said drill shaft and said drill bit permitting assembly and disassembly of said drill bit to and from said drill shaft, said releasable interconnecting means being formed such that said bore passing through said drill bit is aligned with said bore passing through said drill shaft when said drill bit is assembled to said drill shaft, said releasable interconnecting means comprising a tongue-and-groove interconnection; said drill shaft comprising a central body portion, and a tongue portion formed at said other end of said drill shaft and spaced slightly forward of said central body portion, wherein a pair of locking slots are formed in the space between said tongue portion and said central body portion of said drill shaft.

12. A modular drill assembly comprising:

a drill bit having a cutting edge at a first end thereof, and having a bore extending axially completely through said drill bit;

a drill shaft having mounting means at a first end thereof for mounting said drill shaft on a drill tool, and having a bore extending axially through said drill shaft; and

releasable interconnecting means formed on second ends of said drill bit and said drill shaft permitting assembly and disassembly of said drill bit to and from said drill shaft, said interconnecting means being formed such that said bore extending through said drill bit is aligned with said bore extending through said drill shaft when said drill bit is assembled to said drill shaft;

wherein said releasable interconnecting means comprises a tongue-and-groove interconnection means disposed on said second ends of said drill bit and said drill shaft; and

wherein a tongue portion is disposed on one of said second ends and a groove portion is disposed in the other of said second ends; and

wherein said other of said second ends is provided with a counterbore, and

spring means protrude from said counterbore to engage said tongue portion when said drill bit and said drill shaft are assembled together.

13. A modular drill assembly comprising:

a drill bit having a cutting edge at a first end thereof, and having a bore extending axially completely through said drill bit;

a drill shaft having mounting means at a first end thereof for mounting said drill shaft on a drill tool, and having a bore extending axially through said drill shaft; and

releasable interconnecting means formed on second ends of said drill bit and said drill shaft permitting assembly and disassembly of said drill bit to and from said drill

shaft, said interconnecting means being formed such that said bore extending through said drill bit is aligned with said bore extending through said drill shaft when said drill bit is assembled to said drill shaft;

wherein said releasable interconnecting means comprises a tongue-and-groove interconnection means disposed on said second ends of said drill bit and said drill shaft; and

wherein a tongue portion is disposed on one of said second ends and a groove portion is disposed in the other of said second ends; and

spring means protrude from said counterbore to engage said groove portion when said drill bit and said drill shaft are assembled together.

* * * * *

US005499984A

United States Patent [19]

Steiner et al.

[11] **Patent Number: 5,499,984**

[45] **Date of Patent: Mar. 19, 1996**

[54] **UNIVERSAL MODULAR REAMER SYSTEM**

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[73] Assignee: **Snap-on Incorporated**, Kenosha, Wis.

[21] Appl. No.: **224,046**

[22] Filed: **Apr. 7, 1994**

[51] **Int. Cl.**[6] **A61B 17/16**

[52] **U.S. Cl.** **606/80**; 606/79; 408/713

[58] **Field of Search** .... 606/79, 80, 81, 606/91; 403/326, 329, 289, DIG. 4; 408/276, 713; 211/69, 60.1

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Primary Examiner—Stephen C. Pellegrino
Assistant Examiner—Scott Markow
Attorney, Agent, or Firm—Emrich & Dithmar

[57] **ABSTRACT**

A medullary reaming system includes a flexible, hollow, tubular shaft formed of a nickel-titanium alloy having one end coupled to a rotary drive and having the other end coupled to a cutting head by means of a male connector on the shaft engageable in a female connector on the head. The female connector is a tubular shank with diametrically opposed slots in the outer surface thereof, while the male connector has flexible arms with latch tabs engageable in the slots to latch the head to the shaft. A support has a plurality of notches for respectively storing cutting heads. The head shank is received in the notch with the notch edges received in the shank slots, so that when the male connector on the shaft is inserted into the shank the notch edges prevent latching of the head to the shaft until the head is removed from the support.

7 Claims, 1 Drawing Sheet

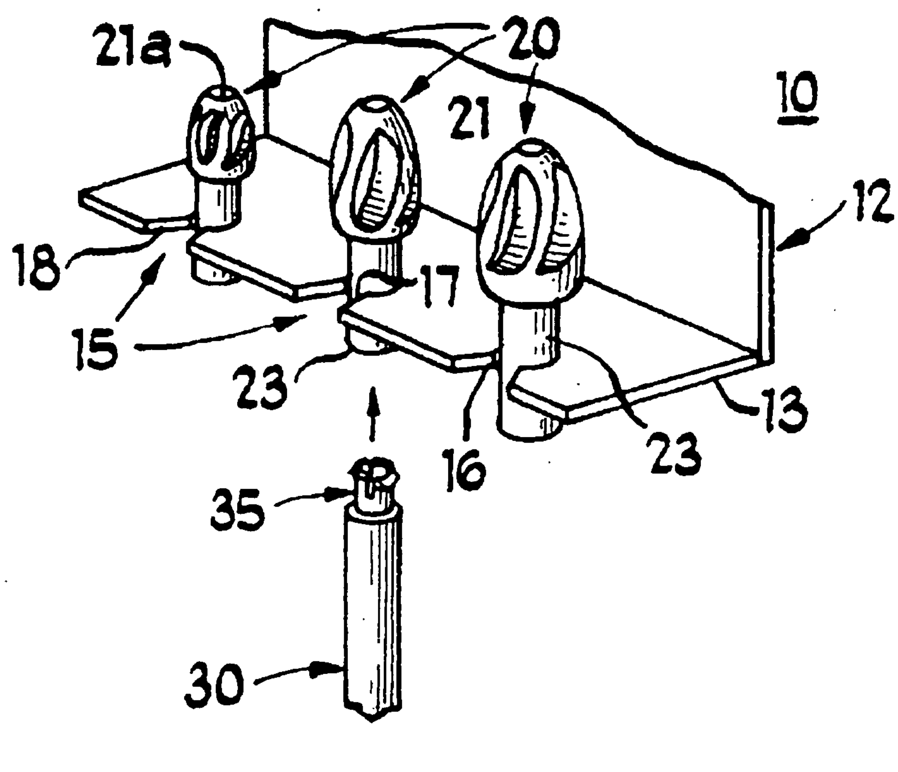
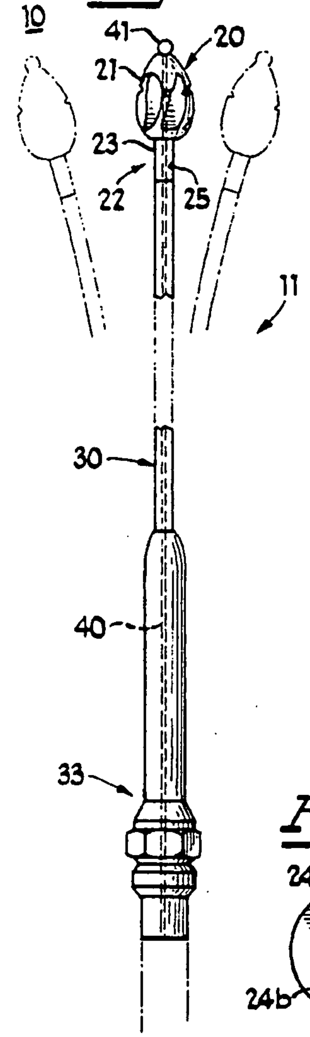


Fig 1



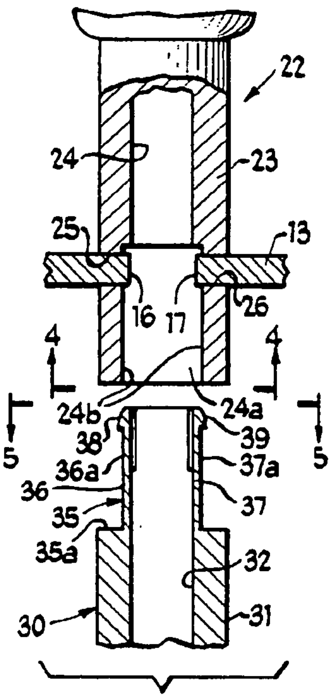


Fig 3

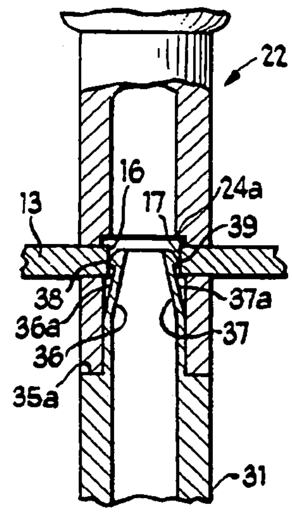


Fig 6

Fig 4

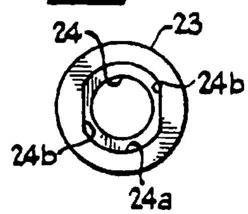
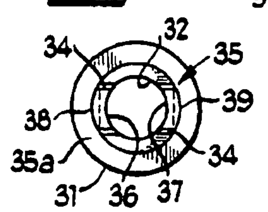


Fig 5



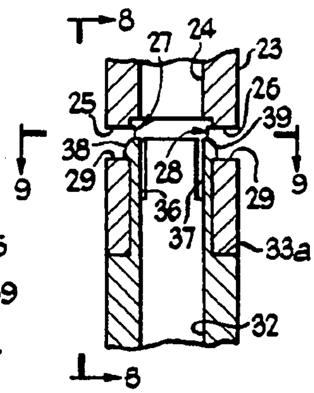


Fig 7

Fig 2

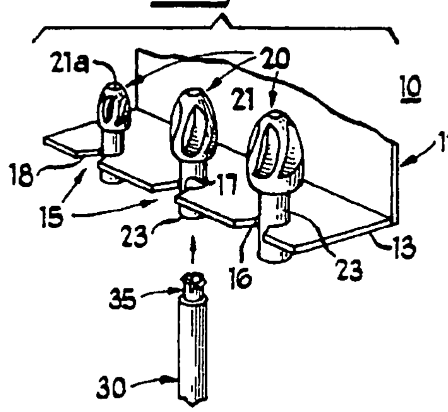
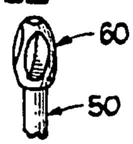


Fig 10



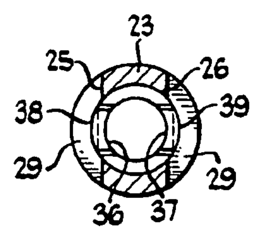


Fig 9

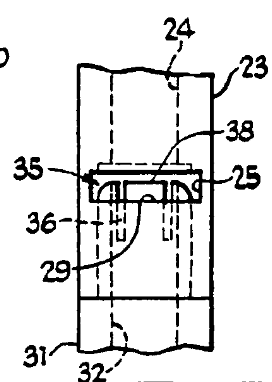


Fig 8

UNIVERSAL MODULAR REAMER SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to medullary reaming systems and to flexible drive shafts therefor.

2. Description of the Prior Art

Medullary reamers are used to enlarge the medullary canals of bone for various reasons. The medullary canals of bone typically have some degree of curvature and, for this reason, are almost always prepared with reamers having a flexible shaft.

One type of prior flexible medullary reamer shaft consists of a spiral or helically wound metal wire or strip which comprises the shaft of the reamer. A disadvantage of this type of shaft is that the reamer can be operated only in the forward mode of rotation. If the reamer is reversed, which is occasionally necessary in order to free a lodged reamer, for example, the shaft unwinds, damaging the shaft. Another disadvantage of this spiral shaft design is that the voids between the shaft coils can trap blood and tissue, making it extremely difficult to thoroughly and properly clean and sterilize the shaft after use. Another disadvantage is that if the cutting head experiences unusually high resistance, the driving torque will accumulate in the shaft as its coils close and then, when it overcomes the resistance to the head, will be released in a sudden burst, causing the cutting head to jump or spin ahead rapidly in an uncontrolled fashion. Such irregular movement of the cutting head may damage the bone.

Another type of medullary reamer shaft comprises a plurality of parallel, flexible elements joined together at their opposite ends by means of a welded or soldered connection. Such a shaft construction suffers from most of the same disadvantages as the helically coiled shaft described above. Another disadvantage occurs in attempting to utilize the central bore of the reamer, to receive a long, small diameter guide wire, which had previously been inserted into the medullary canal to act as a track for the advancing reamer. Except at its respective ends, this parallel-element reamer shaft lacks a well-defined and bordered central bore, making it difficult to prevent the guide wire from exiting the reamer in the area of the free standing shaft wires during the initial positioning of the guide wire within the reamer.

To overcome many of these disadvantages, there has also been provided a hollow tubular shaft formed of synthetic plastic material or a fiber-reinforced composite material. However, plastic shafts may lack the necessary torsional strength. Also, the reamer is autoclaved often and plastic will ultimately fail. A disadvantage of fiber-reinforced composite shafts is that, on failure, there is a danger that fibers will enter the blood stream.

Also, in prior medullary reamers the cutting head has been fixed to the flexible shaft, permanently by suitable bonding or the like. Thus, the head and the shaft form an integral unit and, when it is desired to use a different size cutting head, an entire reaming unit must be substituted. It is known to attach cutting heads to the shaft by suitable fasteners, such as a set screw, but this requires handling and the use of suitable tools.

SUMMARY OF THE INVENTION

It is a general object of the invention to provide an improved medullary reaming system which avoids the disadvantages of prior systems while affording additional structural and operating advantages.

An important feature of the invention is the provision of a medullary reamer with a flexible drive shaft which provides uniform transmission of energy to a cutting head in forward and reverse directions and which is easy to clean.

In connection with the foregoing feature, a further feature of the invention is the provision of a reamer shaft of the type set forth which minimizes the risk of body contamination.

Another feature of the invention is the provision of a reaming system which permits quick and easy mounting of any of a plurality of different cutting heads on a shaft without the use of tools and without manual handling of the cutting head

In connection with the foregoing feature, a further feature of the invention is the provision of a reaming system of the type set forth which affords automatic releasable latching of a cutting head to the shaft.

Certain ones of these and other features of the invention are attained by providing in a medullary rotational reamer having a flexible shaft with a cutting head at one end and an adaptor piece at its opposite end for connecting the shaft to a rotational drive element thereby causing rotation of the shaft, the improvement comprising: the flexible shaft being comprised of a metal alloy including titanium.

Still other features of the invention are attained by providing a modular medullary rotational reaming system comprising: a flexible shaft having a drive coupling portion at one end thereof for connecting the shaft to a rotational drive element to cause rotation of the shaft and, a first head coupling portion at the other end thereof, first latch structure on the first head coupling portion movable between latching and unlatching conditions, a cutting head having a second head coupling portion thereon including second latch structure, and a support for storing the cutting head in a supported position readily accessible to a user, the first and second head coupling portions being mateably engageable with each other in a coupled condition for interconnecting the head and the shaft, the support being engageable with the first latch structure for holding it in its unlatching condition when the first and second head coupling portions are engaged in their coupled condition while the cutting head is held on the support, the first latch structure being responsive to removal of the cutting head from the support while the first and second head coupling portions are engaged in their coupled condition for moving to the latching condition, thereby to latch the cutting head to the shaft.

The invention consists of certain novel features and a combination of parts hereinafter fully described, illustrated in the accompanying drawings, and particularly pointed out in the appended claims, it being understood that various changes in the details may be made without departing from the spirit, or sacrificing any of the advantages of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For the purpose of facilitating an understanding of the invention, there is illustrated in the accompanying drawings a preferred embodiment thereof, from an inspection of which, when considered in connection with the following description, the invention, its construction and operation, and many of its advantages should be readily understood and appreciated.

FIG. **1** is a fragmentary, side elevational view of the reamer of a medullary reaming system in accordance with the present invention, with portions broken away and show-

ing different positions in phantom to illustrate the flexibility of the shaft;

FIG. 2 is a fragmentary, perspective view of the support of the reaming system holding a plurality of cutting heads and illustrating insertion of the reamer shaft;

FIG. 3 is an enlarged, fragmentary view in partial vertical section showing the female connector of a cutting head held on the support with the male connector on the shaft about to be inserted;

FIG. 4 is an end view of the female connector taken along the line 4—4 in FIG. 3;

FIG. 5 is an end view of the male connector taken along the line 5—5 in FIG. 3;

FIG. 6 is a view similar to FIG. 3, illustrating the male and female connectors in their coupled condition;

FIG. 7 is a view similar to FIG. 6, illustrating the latching engagement of the male and female connectors after removal from the support;

FIG. 8 is a fragmentary, side elevational view taken along the line 8—8 in FIG. 7;

FIG. 9 is a sectional view taken along the line 9—9 in FIG. 7; and

FIG. 10 is a fragmentary perspective view of a reamer with a fixed cutting head.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2, there is illustrated a reaming system **10** in accordance with the present invention. The system **10** includes a reamer **11**, comprising a cutting head **20** fixed to the end of a flexible shaft **30**, and a support **12** adapted for holding a plurality of heads **20** in a support position for ready access by a user. Referring to FIG. 2, the support **12** includes a bracket **13** which may be in the form of a flat plate having a plurality of support notches **15** formed therein. Each of the notches **15** has a part-circular inner end and a pair of parallel notch edges **16** and **17** which have outwardly tapered portions **18** at their outer ends. Each of the cutting heads **20** has a head body **21**, which is a toothed or fluted cutting element having an axial bore **21*a*** therethrough. Integral with the head body **21** at its tail end is a coupling portion in the nature of a female connector **22**, which is preferably in the form of a cylindrical tubular coupling shank **23**. Referring also to FIGS. 3, 4 and 7, the coupling shank **23** has an axial bore **24** therethrough with an enlarged-diameter counterbore **24*a*** at its distal end, the counterbore **24*a*** being provided with parallel flats **24*b*** along diametrically opposite sides thereof. Respectively formed in the coupling shank **23** at diametrically opposed locations adjacent to the flats **24*b*** are lateral slots or grooves **25** and **26**, which are formed as chords of the coupling shank **23** and are sufficiently deep to communicate with the counterbore **24*a*** adjacent to its inner end for respectively defining radial apertures **27** and **28** (FIG. 7). The lower sides of the slots or grooves **25** and **26**, as viewed in FIG. 7, form latch keeper shoulders **29** for a purpose to be explained more fully below.

Referring also to FIGS. 5, 6, 8 and 9, the flexible shaft **30** is in the nature of a cylindrical tubular member having a cylindrical outer surface **31** and an axial bore **32** therethrough. The shaft **30** may have any desired length, depending upon the particular application, but may typically be in the range of from 12 to 20 inches. It is a significant aspect of the invention that the shaft **30** is formed of a titanium alloy and, more specifically, of a nickel-titanium alloy of a

type which has considerable flexibility. Preferably, the nickel-titanium alloy is "super elastic" alloy having a maximum recoverable strain of approximately 8%, i.e., the material can be strained up to 8% and will still elastically return to its original configuration. There results a flexible shaft **30** which has great torsional strength and yet provides the flexibility necessary for medullary reaming operations. The monolithic metal structure precludes any release of fibrous material or the like in the event of failure of the shaft. In a constructional model of the invention, the flexible shaft **30** is formed of a nickel-titanium alloy of the type sold by Raychem under the designation TINEL® Alloy BB.

The flexible shaft **30** is coupled at one end thereof by a drive coupler or adaptor **33** to an associated source of rotational drive power (not shown) for rotating the shaft about its axis, all in a known manner. Integral with the shaft **30** at its other end and projecting axially therefrom is a coupling structure in the nature of a male connector **35** of reduced cross-sectional area, so that the connector **35** cooperates with the adjacent end of the shaft **30** to define therebetween an annular shoulder **35*a***. The male connector **35** is basically cylindrical in shape and has a pair of parallel slots **34** extending thereacross at the distal end thereof as chords thereof, thereby to form two diametrically flexible arms **36** and **37**, respectively having flattened outer surfaces **36*a*** and **37*a*** along most of their length. The flattened surfaces **36*a*** and **37*a*** terminate short of the distal ends of the arms **36** and **37** so as to define laterally outwardly projecting latch fingers or tabs **38** or **39**, respectively, on the arms **36** and **37**.

In operation, a plurality of the cutting heads **20** are preferably supported on the support **12**, as illustrated in FIG. 2. The cutting heads **20** all have identical coupling shanks **23**, but may have different size head bodies **21**. The coupling shanks **23** are respectively received in the support notches **15**. The notch edges **16** and **17** are spaced apart a distance less than the outer diameter of the coupling shank **23** and are respectively received in the lateral slots or grooves **25** and **26** of the coupling shank **23**, as is best illustrated in FIGS. 2, 3 and 6. The distance between the notch edges **16** and **17** is such that, in this supported position, they will respectively extend radially inwardly of the coupling shank **23** at least as far as the flats **24*b***. It will be appreciated that, when the cutting heads **20** are thus supported on the support **12**, they are effectively restrained against axial movement. While, in the illustrated embodiment, the support **12** is oriented so that the supported coupling shanks **23** are disposed substantially vertically, it will be appreciated that other orientations could be used for ease of access, depending upon the particular application.

When a user wishes to attach a particular cutting head **20** to the flexible shaft **30**, the male connector **35** is aligned beneath the selected cutting head **20**, as illustrated in FIGS. 2 and 3, and is rotationally oriented so that the flexible arms **36** and **37** are, respectively, aligned beneath the flats **24*b*** of the coupling shank **23**. The male connector **35** is then inserted into the female connector **22** in the direction of the arrow in FIG. 2 to the coupled condition illustrated in FIG. 6, wherein the distal end of the coupling shank **23** bottoms against the shoulder **35*a*** on the shaft **30**. It will be appreciated that the arms **36** and **37** will flex to permit their insertion into the counterbore **24*a*** of the coupling shank **23** and, as was indicated above, the support bracket **13** will firmly hold the cutting head **20** against axial movement in response to this insertion. In the coupled condition of FIG. 6, the latch fingers or tabs **38** and **39** will be respectively disposed opposite the lateral slots or grooves **25** and **26** in

the coupling shank **23**, but will be deflected out of those slots or grooves to an unlatching condition shown in FIG. **6**, wherein they are prevented from engagement in the slots **25** and **26** by the notch edges **16** and **17** of the support bracket **13**.

When the parts have been joined in the coupled condition illustrated in FIG. **6**, the user then pulls the flexible shaft **30** laterally outwardly to remove the cutting head **20** from the support bracket notch **15**. As the coupling shank **23** clears the notch **15**, the flexible arms **36** and **37** resiliently snap back to their normal latching conditions, moving the latch fingers or tabs **38** and **39** respectively into latching engagement with the latch keeper shoulders **29**, as illustrated in FIGS. **7–9**, thereby firmly latching the cutting head **20** to the flexible shaft **30**.

It will be appreciated that, when it is desired to change cutting heads, the user simply moves the coupling shank **23** of the coupled cutting head **20** back into its supported position in the corresponding notch **15** in the support bracket **13**. As the notch edges **16** and **17** reenter the lateral slots or groove **25** and **26** on the coupling shank **23** they deflect the flexible arms **36** and **37** back to their unlatching conditions illustrated in FIG. **6**, thereby permitting easy removal of the male connector **35** from the female connector **22** for reattachment to another cutting head **20**.

It can be seen that the axial bore **32** through the flexible shaft **30** continues through the male connector **35**, and the axial bore **24** through the coupling shank **23** is continuous with the axial bore **21***a* through the cutting head body **21**. Thus, when the cutting head **20** is mounted on the flexible shaft **30**, as is illustrated in FIG. **1**, there is a continuous axial bore through the entire assembly, in standard fashion, for accommodating a guide wire **40**. In use, as the reamer **11** is passed through a medullary canal it is slid along the guide wire **40** which has been preinserted in the canal, the guide wire **40** having an enlarged knob **41** at its distal end sized so as not to pass through the axial bore in the reamer **11**, for purposes of retrieving the reamer, all in a known manner.

While, in the preferred embodiment, the cutting heads **20** are removably coupled to the flexible shaft **30**, it will be appreciated that the flexible shaft of the invention could be provided with a fixed cutting head. Thus, in FIG. **10** there is shown a flexible shaft **50**, which may be the same as the shaft **30** except that it lacks the male connector **35**, to which a cutting head **60** is fixedly Secured by any suitable means.

From the foregoing, it can be seen that there has been provided an improved reaming system which has a reamer with a flexible shaft of great torsional strength while minimizing the chance of contamination and, at the same time, is modular so as to provide a simple and effective means for removably connecting the reamer shaft to a selected one of a plurality of different cutting heads without the use of tools.

We claim:

1. A modular medullary rotational reaming apparatus comprising: a flexible shaft having a drive coupling portion at one end thereof for connecting said shaft to a rotational drive element to cause rotation of the shaft and having a first head coupling portion at the other end thereof, first latch structure on said first head coupling portion movable between latching and unlatching conditions; means biasing said first latch structure to the latching condition; a cutting head having a second head coupling portion thereon including second latch structure; and a support for storing said cutting head in a supported position readily accessible to a user; one of said head coupling portions including a socket having an axis and the other of said head coupling portions including a plug axially receivable in said socket, said first and second head coupling portions being non-rotationally mateably engageable with each other in a coupled condition for interconnecting said head and said shaft, said support including retaining means engageable with said first latch structure for holding it in its unlatching condition when said first and second head coupling portions are engaged in their coupled condition while said cutting head is held on said support, said first latch structure being responsive to removal of said cutting head from said support while said first and second head coupling portions are engaged in their coupled condition for moving to the latching condition, thereby to latch said cutting head to said shaft.

2. The reaming apparatus of claim **1**, wherein said first latch structure includes a resilient flexible arm having a latch finger thereon, said second latch structure comprising a latch keeper engageable by said latch finger.

3. The reaming apparatus of claim **2**, wherein said second head coupling portion includes a tubular shank projecting from said head, said second latch structure including a radial aperture formed in said shank.

4. The reaming apparatus of claim **3**, wherein said shank has a slot formed in the outer surface thereof and communicating with said radial aperture, said support having a notch formed therein and defining a notch edge, said shank being receivable in said notch when said cutting head is disposed in said supported position with said notch edge disposed in said slot for preventing axial movement of said cutting head and for preventing engagement of said latch finger in said radial aperture.

5. The reaming apparatus of claim **1**, wherein said support includes means for storing a plurality of cutting heads in supported positions readily accessible to a user.

6. The reaming apparatus of claim **1**, wherein said support includes means engageable with said cutting head in its supported position for preventing axial movement of said head.

7. The reaming apparatus of claim **1**, wherein said shaft is formed of a nickel-titanium alloy.

* * * * *

United States Patent [19]

Matthews et al.

[11] **Patent Number: 4,706,659**

[45] **Date of Patent: Nov. 17, 1987**

[54] **FLEXIBLE CONNECTING SHAFT FOR INTRAMEDULLARY REAMER**

[75] Inventors: **Larry S. Matthews; Steven A. Goldstein**, both of Ann Arbor, Mich.

[73] Assignee: **Regents of the University of Michigan, Ann Arbor, Mich.**

[21] Appl. No.: **678,682**

[22] Filed: **Dec. 5, 1984**

[51] **Int. Cl.**[4] **A61F 5/04**

[52] **U.S. Cl.** .... **128/92 VD; 128/83; 464/173; 464/179; 464/57**

[58] **Field of Search** .... **128/92 E, 83; 464/19, 464/173, 179, 57**

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Assistant Examiner—Wenceslao J. Contreras

Attorney, Agent, or Firm—Sherman and Shalloway

[57] **ABSTRACT**

Disclosed herein are embodiments of a flexible connecting shaft for an intramedullary reamer. In each embodiment, several short segments or links are attached together to form an elongated flexible shaft which shaft is designed, due to the specific attachment means for the links, to bend along its longitudinal axis while transmitting torque without any lag in such transmission. A link at one end of the flexible shaft as made by a plurality of the links includes means provided for attachment to a torque providing device such as an electric motor. At the opposite end of the shaft, the last link includes structure thereon enabling connection to a drill bit. The various embodiments disclose different ways of interconnecting the links.

4 Claims, 11 Drawing Figures

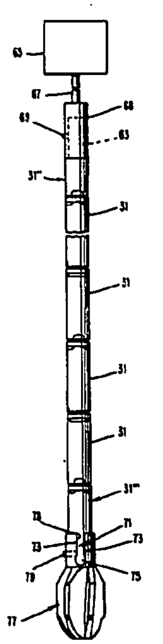
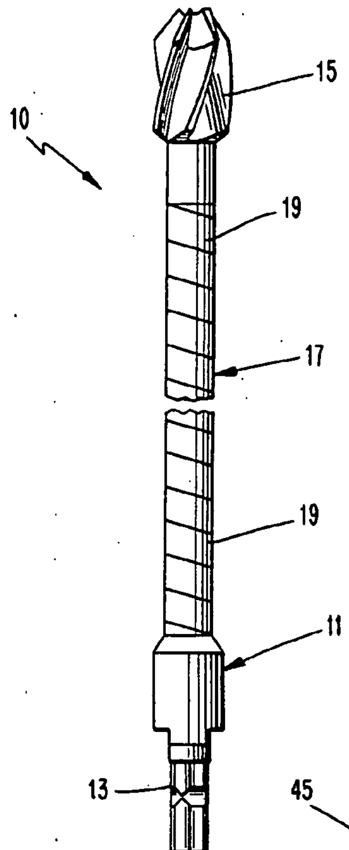


Fig. 1
PRIOR ART



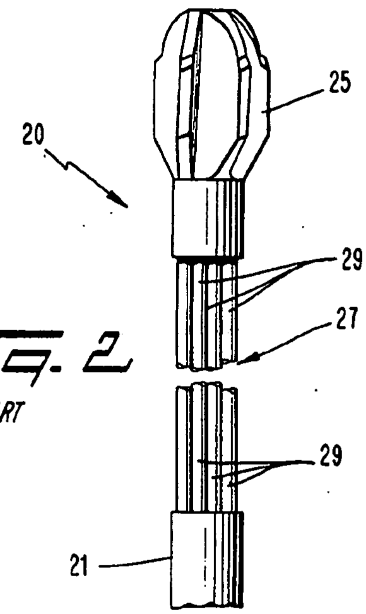


Fig. 2
PRIOR ART

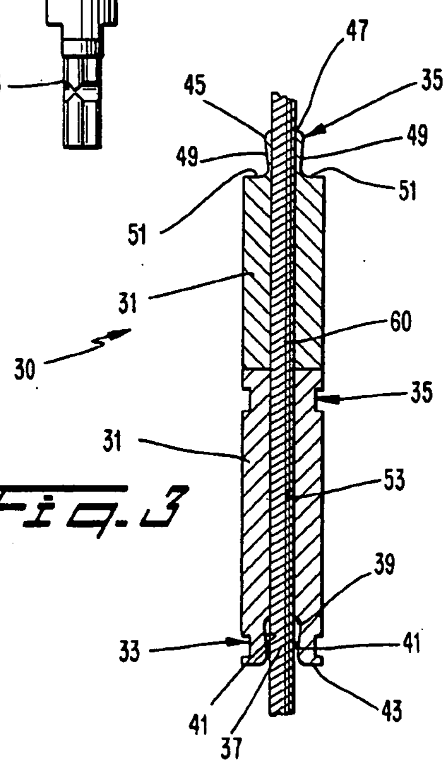


Fig. 3

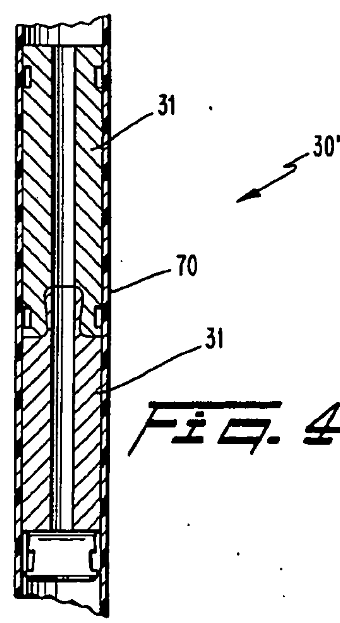


Fig. 4

Fig. 5

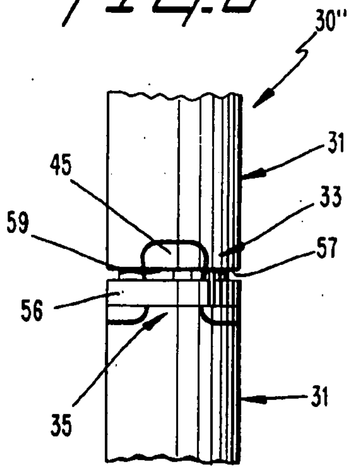


Fig. 6

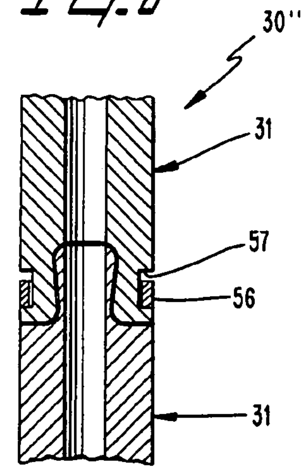


Fig. 9

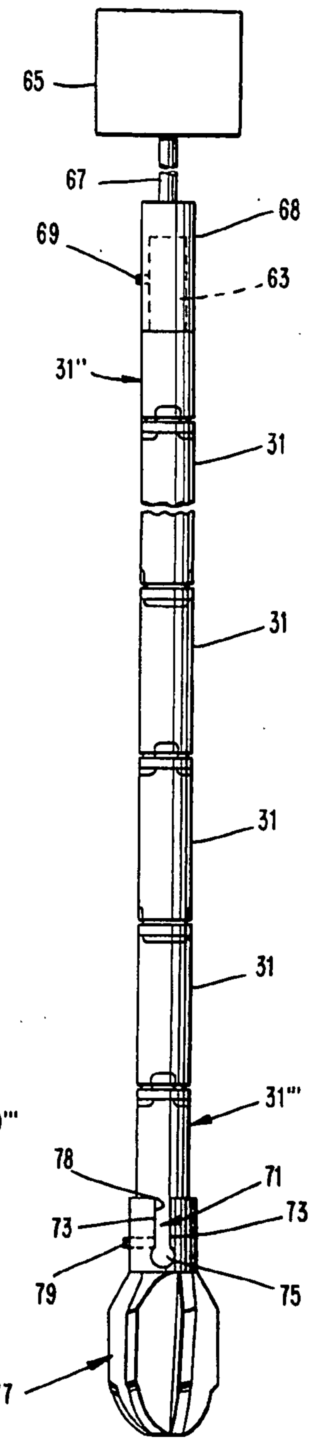


Fig. 7

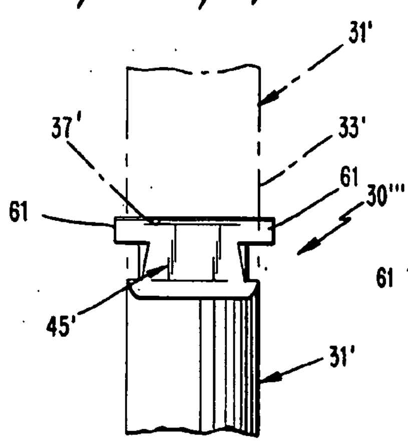
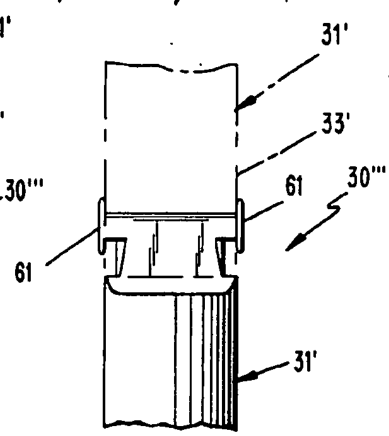


Fig. 8



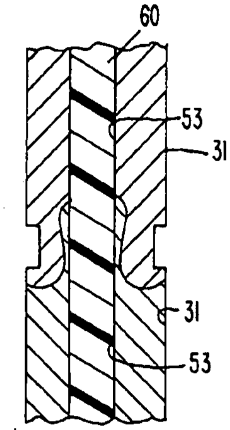


Fig. 10

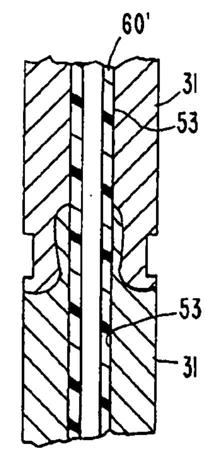


Fig. 11

FLEXIBLE CONNECTING SHAFT FOR INTRAMEDULLARY REAMER

BACKGROUND OF THE INVENTION

Many fractures of long bones can be satisfactorily stabilized by the surgical insertion of a shaft, rod or nail into the intramedullary canal of the bone. Since the natural canal is irregular in internal diameter and configuration from end to end, and since all intramedullary fixation devices gain strength with increases in diameter, most surgical procedures call for incremental reaming with sequentially used reamers having 0.5 mm or 1.0 mm inmcreases in outside diameter. Because the shafts of most long bones are bent or curved along their longitudinal axes, flexible shafts that can bend to follow this naturally curved path while transmitting torque are necessary in the art of intramedullary reaming so as to prevent the reamer from cutting through the wall or cortex of the bone. If the reamer shaft is inflexible and thereby does not follow the natural curvature of the bone, the reamer head may in fact cut through the wall or cortex of the bone being reamed.

Presently marketed flexible intramedullary reamer shafts are designed in such manner that they store rotational energy in a spring manner whenever the cutting head stops or gets caught by the bone structure. When this happens, the driving motor continues to turn the proximal end of the shaft to thereby increase the torque and to thereby store energy in the shaft until the force exerted by the shaft exceeds the force which is retaining the cutter head. At this point, the cutter head becomes dislodged thereby allowing the release of the stored rotational energy so that the cutter head springs, jumps, or spins ahead rapidly in an uncontrollable fashion within the bone. In many cases, the above described scenerio repeats itself over and over again to thereby cause what is known in the art as "chatter". These irregular, uncontrollable movements of the reamer head caused by the spring-like shaft may damage the bone and act to greatly increase the risks of surgical complications. Two examples of prior art constructions exhibiting the above described characteristics are illustrated herein in FIGS. 1 and 2 respectively, and will be described in greater detail hereinafter.

One particular problem occurs frequently in the prior art shaft shown in FIG. 1. This shaft may only be used in a forward rotational direction since if it is inadvertently or intentionally used in reverse, the spring-like shaft may unwind and virtually self-destruct. This often occurs when a surgeon attempts to reverse the rotational motion of the cutter head to dislodge it. In a further problem typical of prior art reamer shafts which are made of multiple strands of wire, cable, or strap material wrapped in a helical fashion, blood may enter the spaces between the various associated parts thereof, which blood or tissue may not be readily removed and could in fact become a danger to subsequent patients.

SUMMARY OF THE INVENTION

The present invention overcomes the deficiencies and problems evident in the prior art as described hereinabove by combining the following features into an integral longitudinally flexible and torsionally inflexible reamer shaft as follows:

(a) In each embodiment of the present invention, the flexible connecting shaft for an intramedullary reamer is comprised of a plurality of short segments or links made of a material such as stainless steel, chrome cobalt molybdenum alloy, titanium, or other metals, and configured from a polygonal or cylindrical rod.

(b) Each segment or link includes a male end and female end with each male end being specifically configured so as to interengage with the female end of an adjacent link.

(c) Each link includes a hole extending axially therethrough and when the links are fitted together with respective male ends inserted into respective female ends, the holes formed in respective links may be aligned with one another.

(d) In a first embodiment of the present invention, the links may be connected together to form a reamer shaft by inserting through the aligned holes in the individual links a flexible rod. This rod will hold the links together while allowing the flexing of the shaft about the longitudinal axis thereof.

(e) In a second embodiment of the present invention, instead of a flexible rod inserted through the aligned holes, the loosely assembled links may be inserted into an elongated flexible tube which will hold the links together while allowing the desired flexing thereof.

(f) In a third embodiment, the links may be held together with circumferentially installed securing rings. In this embodiment, the respective male and female ends of adjacent links are provided with portions of a circumferential recess which when the links are assembled to one another forms a continuous circumferential recess including portions of the respective male and female ends of the adjacent links. A securing ring is positioned around this continuous recess to thereby hold the links together while allowing the desired flexing thereof.

(g) In a further embodiment of the present invention, the links may be assembled through deformation of lateral portions of the male ends of the respective links. In this embodiment, the male ends are made slightly wider than the respective female ends so that when the links are loosely assembled to one another, the male ends slightly protrude out of the sides of the respective female ends. After loosely assembling the links together, the portions of the male ends protruding laterally outwardly from the female ends are deformed by inpacting them with a tool such as a hammer so as to prevent disassembly while allowing the desired flexing of the shaft formed by the links.

Accordingly, it is a first object of the present invention to provide a reamer shaft which will flex, bend or curve to follow the natural intermedullary canal of the bone while transmitting reaming torque effectively.

It is a further object of the present invention to design a reamer shaft which will have considerable rotational or torsional stiffness so that it will not store and then irregularly release rotational energy.

It is a further object of the present invention to provide a reamer shaft which will flex, curve or bend while transmitting torque and while at the same time reaming naturally curved long bones without cutting through the cortex or side wall of the bones. It is a further object of the present invention to provide a reamer shaft which may easily be cleaned and sterilized.

It is a yet further object of the present invention to provide a reamer shaft which may be operated both in the forward and reverse directions thereof with equal effectiveness.

These and other objects, features, advantages and aspects of the present invention will be better understood with reference to the following detailed description of the preferred embodiments when read in conjunction with the appended drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a side view of a first prior art construction of a reamer shaft.

FIG. 2 shows a side view of a second prior art reamer shaft.

FIG. 3 shows a cross-sectional view of a portion of the reamer shaft in accordance with the present invention with a first embodiment of link securement being shown.

FIG. 4 shows a cross-sectional view of a portion of the reamer shaft in accordance with the present invention rotated 90° with respect to the cross-section of FIG. 1 and showing a second embodiment of securement of links together.

FIG. 5 shows a side view of a portion of a reamer shaft in accordance with the present invention with a third embodiment of link securement being shown.

FIG. 6 shows a cross-sectional view through the embodiment of FIG. 5.

FIG. 7 shows a cross-sectional view of a portion of reamer shaft made in accordance with the present invention and showing a fourth embodiment of link securement specifically shown before deformation thereof.

FIG. 8 shows a view similar to the view shown in FIG. 7 but after deformation has taken place.

FIG. 9 shows a reamer shaft made in accordance with the present invention and particularly showing details of coupling means at each end thereof.

FIG. 10 shows a cross-sectional view along the line 10—10 of FIG. 3.

FIG. 11 shows a cross-sectional view corresponding to that of FIG. 10, but with an alternative link securement.

SPECIFIC DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference now to FIG. 1, a first prior art construction will be described. The device 10 shown in FIG. 1 includes a connection member 11 having an end 13 provided for attachment to a drive means such as an electric motor. At the other end of the device 10, a drill bit 15 is provided so as to enable drilling of an intramedullary canal. Connecting the bit 15 and the connection means 11 is an elongated shaft 17 which is made of a long strip of metal wound in a spiral-like fashion to form coils 19 which extend throughout the longitudinal extent of the shaft 17. The shaft 17 has not been found to be an effective means of transmitting torque from the connection means 11 to the drill bit 15 since when the drill bit 15 encounters an obstruction tending to stop its motion, the shaft 17 by virtue of its coil-like construction, allows the connection means 11 to be moved by the drive motor with respect to the bit 15, to thereby enable energy to be stored up therein. When the energy stored up in the shaft 17 exceeds the forces which are retaining the bit 15 in a stationary position, the bit 15 will then jump forward which in some cases may cause damage to the structure of the bone. In another disadvantage of the prior art construction shown in FIG. 1, if the bit 15 encounters an obstruction which is not easily removed, the surgeon operating the device 10 may be tempted to reverse the direction of operation thereof to loosen the bit 15 from the obstruction. If this is done, and the bit 15 is not removed from the obstruction thereby, the reversal of the motion of the drive motor will cause the shaft 17 to uncoil, thereby ruining the shaft 17 while at the same time increasing the potential for damage to the surrounding bone tissues. In a further aspect, if sufficient reverse motion of the connection means 11 is made with respect to the bit 15, the shaft 17 might become sufficiently widened so as to prevent its extraction from the opening formed by the bit 15. Accordingly, several disadvantages in the device 10 are self-evident.

FIG. 2 shows a further prior art device designated with reference numeral 20 which is seen to include a connection means 21, a drill bit 25, and shaft means 27 interconnecting the connection means 21 and the drill bit 25. The shaft means 27 is comprised of a plurality of elongated parallel annularly disposed individual elements 29, preferably made of circular cross-section. The elements 29 are provided so as to transmit torque from the connection means 21 to the drill bit 25, however, the disadvantage of this design of shaft means 27 is that the shaft means 27 may be twisted during situations when the drill bit 25 is stuck within the intramedullary canal while the connection means 21 is still being rotated by a rotary drive means. In this situation, similarly to the FIG. 1 construction, the device 20 may buck and chatter with the shaft means 27 alternatively building up energy and releasing it to the drill bit 25. Accordingly, the use of the device 20 which is the subject of U.S. Pat. No. 3,554,192 to Isburner may prove disadvantageous.

With reference now to FIGS. 3-9, several embodiments of the present invention, each of which overcomes the disadvantages found in the prior art, will be discussed.

With reference first to FIG. 3, a portion of the shaft 30 of the present invention will be discussed along with a first embodiment of interconnection thereof. As shown in FIG. 3, the shaft 30 in accordance with the present invention is comprised of a plurality of links 31 connected together end to end to form the shaft 30. Each link 31 includes a female end 33 and a male end 35. As seen in FIG. 3, the female end 33 includes a slot 37 including a bottom wall 39 extending substantially perpendicularly to the longitudinal extent of the link 31, and a pair of sides 41 which are closest together at the end 43 of the link 31 and diverge from one another until arriving at the bottom wall 39.

With further reference to FIG. 3, it is seen that the male portion 35 of the link 31 includes a protruding member 45 which includes a top wall 47 also defining the uppermost portion of the link 31 and two sides 49 which are at their furthest distance from one another at the top wall 47 and converge toward one another until arriving at a shoulder formed by the walls 51. As may be seen from comparison of the recess 37 and the protruding member 45, the recess and protruding member are so designed that the protruding member 45 may be laterally slid into the recess 37 with the interaction between the respective walls 41 of the recess 37 and the walls 49 of the protruding member 45 preventing axial disengagement thereof.

The volume created by the recess 37 is slightly greater than the volume displaced by the protruding member 45 so that slight relative motion therebetween is possible to thereby enable the entire shaft 30 to be bent with respect to its normal straight longitudinal

axis. However, the elongated nature of the recess 37 and the protruding member 45 in a direction perpendicular to the longitudinal axis of the links 31 causes the relative motion between the protruding members 45 and their respective recesses 37 to be extremely slight. Accordingly, when a link at a first end of the shaft 30 is twisted by means such as an electric rotary motor, torque is transmitted to a link at a second end of the shaft 30 substantially simultaneously and directly with virtually no lag therebetween. Accordingly, the shaft 30 of the present invention provides a direct interconnection between a drive means and a drill bit for effective intramedullar reaming.

With further reference to FIG. 3, it is seen that each link 31 includes extending longitudinally therethrough along the axis thereof, a hole 53. When several links are assembled together and longitudinally aligned, a continuous passageway is formed extending from a link at one end of the series of links to a link at a second end of the series of links. With further reference to FIGS. 3 and 10, it is seen that a first embodiment of interconnection of the links together comprises a flexible elongated rod 60 which may be inserted through the passageways 53 formed in the associated links 31 to thereby prevent disassembly of the links 31 comprising the shaft 30. Again, it is stressed, that the only way to disassemble the links 31 from one another is to slide them laterally with respect to one another to thereby disengage the protruding members 45 from the respective recesses 37. As may be seen in FIG. 3, the provision of the flexible rod 60 extending therethrough prevents such lateral movement and thereby prevents disassembly. If desired, the flexible rod 60 may be made of any flexible material such as rubber or plastic which will maintain its flexibility while not being broken by the links 31.

With further reference to FIG. 11, an alternative link ssecurement device may take the form of the tube 60' instead of the rod 60 shown in FIGS. 3 and 10. The tube 60' may be made of any flexible material such as rubber or plastic which will maintain its flexibility while not being broken by the links 31.

With reference now to FIG. 4, a second means for interconnecting the links 31 into a shaft 30 is shown. As shown in FIG. 4, after the links 31 are connected together, a flexible sleeve 70 may be fitted over the links 31 as assembled so as to again prevent relative lateral movement thereof and thereby assemble the links together into a shaft 30. The sleeve 70 may be made of any flexible material any should be sized so as to snugly fit over the exterior walls of the respective links 31. One advantageous way of assembling the sleeve 70 about the links 31 is to provide a sleeve 70 of slightly greater internal dimension than the external dimensions of the links 31 and to thereafter shrink-fit the sleeve 70 over the links 31 so as to complete the assembly. The sleeve 70 is a particularly advantageous means for assembling the links 31 into a shaft 30' since the sleeve 70 prevents any blood or body tissues from entering into spaces formed between the links 31. Accordingly, the shaft 31' formed in this manner is quite easy to sterilize for the purpose of re-use.

FIGS. 5 and 6 show side and cross-sectional views respectively of a third embodiment of reamer shaft designated by reference numeral 30". With reference first to FIG. 5, it is seen that the female end 33 of the upper link 31 is provided with a partial groove 57 and it is further seen that the male end 35 of the lower link member 31 is provided with a further partial groove means 59. When the protruding member 45 is assembled into the recess 37, these partial grooves 57 and 59 align with one another to form a continuous annular groove extending completely circumferentially of the two interengaged links 31. With this continuous groove being formed by the links 31, a ring 56 is deformed into the groove formed by the groove portions 57 and 59 to thereby prevent relative lateral movement of the links 31 to thereby prevent disassembly thereof. Such structure may be provided so as to assemble all of the links together to form a shaft 30".

As may be seen in FIG. 6, the groove as exemplified by groove portions 57 has a slightly longer longitudinal extent than the width of the ring 56 in the direction of the longitudinal axes of the links 31. Accordingly, this dimension difference allows the rings 56 to move slightly up and down along the longitudinal axes of the links 31. In this way, the slight movement between the respective protrusions 45 and recesses 37 as described hereinabove is permitted to thereby allow the bending of the reamer shaft 30" about its normal longitudinal axis while permitting direct torque transmission therethrough as also described hereinabove.

With reference now to FIGS. 7 and 8, a further means for connection of the links together will be described. FIG. 7 shows a portion of a shaft 30'" formed of links 31'. The links 31' differ from the links 31 in that the protruding members 45' thereof have slightly different construction. As seen in FIG. 7, the links 45' include protrusions 61 which extend laterally beyond the lateral extent of the female portion 33' of the associated link. Thus, in assembling the links together, the respective protrusions 45' are inserted into the respective recesses 37' until the respective links 31' are laterally aligned. Thereafter, with reference to FIG. 8, the lateral ends 61 of the protrusion 45' are deformed by a means such as a hammer so as to cause the ends 61 to flatten out. This flattening out of the ends 61 causes them to extend over the edges of the recess 37' to thereby prevent relative lateral movement therebetween. Accordingly, in this manner, the links 31' may be permanently assembled to one another in a manner that enables the links 31' to form a shaft 30'" which may bend with respect to its normal longitudinal axis while allowing direct transmission of torque from a drive means to a drill bit thereof.

With reference now to FIG. 9, a shaft 30 typical of the embodiments described hereinabove is shown with details of connection means thereof shown. With reference to FIG. 9, several links 31 may be joined together in one of the manners disclosed hereinabove to form an elongated reamer shaft 30. At a first end of the shaft 30, a link 31" is provided which includes a normal female end 33 but has its male end replaced with a cylindrical protrusion 63. The cylindrical protrusion 63 is provided so as to enable connection to a motor 65 via a motor shaft 67, a chuck 68 and a set screw 69 extending through the wall of the chuck 68 and engaging the outer surfaces of the cylindrical portions 63 to thereby drivingly interconnect the member 63 and the chuck 68.

With further reference to FIG. 9, it is seen that at the other end of the reamer shaft 30, a link 31'" is provided which includes the normal male end 35 but has its female end replaced with a connection means 71 including flat sides 73 having a substantially cylidnrical member attached to the ends of the sides 73, with the axis of this cylindrical member 75 extending at right angles to the longitudinal extent of the link 31'". A drill bit 77 is provided which includes a recess 78 corresponding to

the protrusion formed by the walls **73** and cylindrical member **75** to thereby enable lateral movement of the bit **77** with respect to the link **31'''** to thereby assembly the bit **77** to the link **31'''**. Thereafter, a means such as a set screw **79** or other means known to those skilled in the art may be utilized to fix the drill bit **77** against relative movement with respect to the link **31'''**.

It is noted that the cylindrical portion **63** and connection means **71** are designed so as to be utilized by chucks **68** and recesses **78** common in the art so as to enable universal application of the teachings of the present invention.

It is further noted, that if desired, the reamer shaft **30** shown in FIG. **9** may be configured so that the link **31''** includes a male end and the link **31'''** includes a female end as desired.

Thus, a reamer shaft has been designed having links thereof made of lengths and diameters selected to allow optimization of the flexibility of the shaft along its longitudinal axis while maintaining the necessary torsional strength. Various modifications, alterations, or changes may be made to the teachings disclosed hereinabove without departing from the intent of the present invention. For example, if desired, the flexible rod **60** and the sleeve **70** may be made of flexible metallic materials or any other material which will act to assemble the links **31** together while allowing the desired flexibility therebetween. Further, the members **63** and **71** may be made of any configuration as desired so as to enable connection of the reamer shaft **30** to the appropriate drive means and drill bit. It is noted that the term "drill bit" is considered to be interchangeable with the term "reamer head" for the purposes of this disclosure. While the invention disclosed herein is not considered to be directly concerned with the methods of reaming the intramedullary canals, it is noted that the present invention is easily usable in conjunction with an appropriate guide wire previously introduced into the intramedullary canal of the bone being reamed as is well known to those skilled in the art. Accordingly, it is to be understood that the present invention should only be limited by the terms of the appended claims.

I claim:

1. A flexible connecting shaft for an intramedullary canal reamer, comprising:

(a) first link means including first connection means for connecting said first link means to drive means;

(b) second link means including second connection means for connecting said second link means to reamer head means; and

(c) further link means interconnecting said first and second link means and including:

(1) a male end adapted to interfit with a female end formed on one of said first link means and said second link means;

(2) a female end adapted to interfit with a male end formed on the other of said first link means and said second link means;

(3) said shaft including fastening means for preventing disconnection of said link means;

(d) said shaft having a longitudinal axis and said link means interacting through structure allowing flexing of said shaft about said axis while substantially preventing relative twisting of any one link means with respect to any other link means, whereby said shaft may directly transmit torque from said drive means to said reamer head means substantially without slippage while said shaft conforms to the specific shape of the canal; said structure including:

(1) each said female end including a slot extending substantially perpendicular to said axis and having a narrowed opening;

(2) each said male end including a protruding member substantially corresponding, in shape, to the shape of said slot but of slightly smaller volume;

(3) said protruding member being insertable into a respective slot in a direction substantially perpendicular to said axis and being constrained from removal axially by said narrowed opening; and

(e) further wherein said fastening means comprises:

(1) each link means including a longitudinal passageway therethrough; and

(2) flexible rod means extending through the passageways in all said link means.

2. The invention of claim **1**, wherein said further link means comprises a plurality of interconnected links.

3. The invention of claim **1**, wherein said further link means includes a plurality of links, each said link including one said male end and one said female end.

4. A flexible connecting shaft for an intramedullary canal reamer, comprising:

(a) first link means including first connection means for connecting said first link means to drive means;

(b) second link means including second connection means for connecting said second link means to reamer head means; and

(c) further link means interconnecting said first and second link means and including:

(1) a male end adapted to interfit with a female end formed on one of said first link means and said second link means;

(2) a female end adapted to interfit with a male end formed on the other of said first link means and said second link means;

(3) said shaft including fastening means for preventing disconnection of said link means;

(d) said shaft having a longitudinal axis and said link means interacting to allow flexing of said shaft about said axis while substantially preventing relative twisting of any one link means with respect to any other link means, whereby said shaft may directly transmit torque from said drive means to said reamer head means substantially without slippage while said shaft conforms to the specific shape of said canal; and

(e) further wherein said fastening means comprises;

(1) each link means including a longitudinal passageway therethrough; and

(2) flexible plastic tube means extending through the passageways in all said link means.

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